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CONTINUOUS-CURRENT DYNAMOS.

CONTINUOUS - CURRENT DYNAMOS

IN THEORY AND PRACTICE.

WITH

DETAILS OF METHODS AND FORMULÆ USED IN CONSTRUCTION.

A Practical Handbook for Designers, Manufacturers, and Users.

BY

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ILLUSTRATED WITH NEARLY 300 DIAGRAMS.

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PREFACE.

The number of English books dealing with the theory and construction of continuous-current dynamos is already by no means inconsiderable, and includes many excellent works—such as those of Gisbert Kapp and Prof. S. P. Thompson. In order to justify the publication of the present volume, a brief sketch of its special characteristics, together with some account of the purposes which it is intended to serve, may not be out of place.

The general and theoretical education of electrical students in England and the United States, however excellent it may be, can hardly be expected to produce finished electrical engineers. Indeed, the problems which occur in practice are not of a kind to admit of introduction into a college curriculum, where the main object must be to impart a theoretical education as complete and many-sided as possible. Thus the student's term of learning is by no means ended when he enters into the sphere of practical work; indeed, it may be said to have only then commenced, since he is then for the first time thrown on his own resources. On the other hand, anyone who has taken this step will remember the difficulty of the transition, and how much valuable time was lost before he made himself at home in his new sphere.

In order to lighten this task, the author has in the present volume brought together all those practical formulæ which are indispensable for the construction or critical examination of continuous-current dynamos. The applications of these formulæ are fully explained by the aid of numerous numerical examples. The text is further supplemented by a large number of illustrations, representing in detail machines which have been actually constructed. It is hoped that the tabular matter and descriptions of these machines will serve to increase the critical knowledge of the reader.

There remains the agreeable task of expressing my best thanks to the various firms, both English and foreign, who have most kindly placed drawings and tables at my disposal. I venture to express the hope that it will be possible for me in a later edition to devote greater attention to English and American machines.

J. Fisher-Hinnen.

Le Raincy, S.-et-O.,
France.

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ERRATA.

Page 14, line 4 from bottom, for "C l B ergs," read "C l B dynes."

Page 17, line 6 from bottom, for "10^7 absolute ergs," read "10^7 ergs per second."

Page 33, line 5, for $\frac{N_1 \pm 2a,}{p}$ read $\frac{N_1 \pm 2p_1.}{p}$

Page 44, last line, read "s = sectional area," etc.

Page 49, line 4, for "*Elektrotechnishe*," read "*Elektrotechnische*."

Page 49, line 19, after "somewhat larger," read "To be quite safe we will take $\eta = 0{\cdot}003$."

Page 61, line 7 from bottom, for "Zimmermann," read "Timmermann."

Page 62, equation (46), for $\frac{645 \times \text{watts lost}}{\text{surface } (1 \times 0{\cdot}3\sqrt{v})}$, read

$$\frac{645 \times \text{watts lost}}{\text{surface } (1 + 0{\cdot}3\sqrt{v})}.$$

Page 68, line 3 from bottom, for "$k = \ldots$," read "$k = \ldots$."

Page 69, line 4 from bottom, for "equation (41)," read "equation (49)."

Page 76, line 6, for "m," read "A."

Page 79, 3rd line in column, under N_2, for "38," read "58."

Page 85, in Fig. 52, for "ohms lost," read "ohmic loss."

Page 88, line 6, for "two thin," read "too thin."

Page 111, line 4, for "10 per cent.," read "10 per 1,000."

Page 119, Fig. 70, for "C_2," read "I_2."

Page 260, line 11, for "Table XI.," read "Table XII."

Page 273, lines 9 and 11 from bottom, for "lineal inch," read "linear inch."

Page 276, line 18, for "Table XIII.," read "Table XII."

Page 322, line 10, for "N," read "N_m."

Page 322, line 11, for "N," read "N_1."

Page 398, heading of third column of table, for "Loss in machinery," read "Loss in machining."

NOTE.

It may be well to remark that the quantity termed the *specific resistance* on page 18, the values of which are given in Table I., page 409, is the resistance of a wire 1 m. long and 1 sq. mm. sectional area. Its value is therefore equal to 10^4 times the quantity generally termed the specific resistance—*i.e.*, the resistance between opposite faces of a centimetre cube of a substance.

CONTINUOUS-CURRENT DYNAMOS

CHAPTER I.

General Theoretical Considerations, and Principles of Dynamo Construction.

A. Formation of Electromagnets.

Magnetic lines of force are generated around any conductor through which a current is passing, and the conductor forms, as it were, the axis of the lines.

Whether, however, we are justified in assuming any real movement along the lines of force is a question as yet undetermined. It is more probable that the lines of force after their generation are motionless, but for simplicity of explanation it is very convenient to assume an encircling movement.

The phenomena produced by lines of force are easily seen if we duly examine the space in close proximity to the conductor. Thus, if an insulated conductor is wound round a magnetisable body, such as an iron rod (Fig. 1), the iron core will, during the passage of a current through the conductor, act as a magnet. Such a magnet is called an electromagnet. The electromagnet has properties similar to those of an ordinary permanent magnet.

Certain conventions have been agreed upon in regard to electromagnets. The end at which the lines of force are assumed to leave the iron is called the north pole, and the end at which the lines are assumed to enter the iron is called the south pole of the magnet. The current in the conductor wound round the iron core is in the same direction as the nds of a watch when a person is facing a south pole, and e opposite direction to the hands of a watch when

facing a north pole. The latter rule was first suggested by Ampère.

The measure of the strength of magnetisation is determined by the number of lines passing through unit surface. The unit surface adopted in scientific works is usually a square centimetre. Thus the unit of magnetisation is one line through a square centimetre.

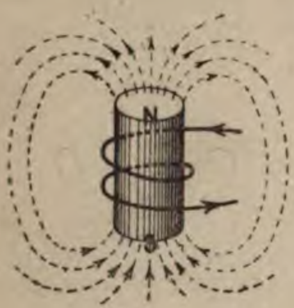

FIG. 1.

The unit pole radiates 4π lines of force, for the surface area of a sphere of 1 cm. radius is 4π square centimetres, and it consequently follows that 4π lines of force pass normally through the entire surface.

Thus, the total number of lines of force which issue from a pole of strength P is $4\pi P$.

The magnetising or, as it is called, the magnetomotive force of the current will be increased if, instead of one turn, a greater number of turns of the conductor be wound continuously round the iron core.

Let C represent the current in amperes which passes through the coil;
L be the length of the coil in centimetres;
N be the number of turns of the conductor round the iron core;

then the magnetomotive force will be—

$$H = \frac{4\pi}{10} \cdot \frac{CN}{L} \quad \text{. . . . . (1)}$$

The number of lines of force per square centimetre in the interior of the coil will be

$$B = \mu H \quad \text{. . . . . . . (2)}$$

where the coefficient μ represents the "permeability" or magnetic conductivity of the medium enclosed in the coil.

If the coil contains no iron, but only air or other non-magnetic substances, then $\mu = 1$.

The permeability of iron varies with its saturation—that

[redacted]

is, with the density of the lines of force passing through it. Generally, according to the degree of saturation, the permeability of iron varies between 50 and 200 times that of air.

Suppose a coil to have a sectional area of S square centimetres, the total number of lines of force will be

$$\phi = \frac{4\,\pi}{10} \cdot \frac{S\,\mu}{L} \cdot C\,N \quad . \quad . \quad . \quad . \quad . \quad (3)$$

or, more generally,

$$\phi = \frac{C\,N}{R} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where R stands for magnetic resistance.

The factor C N is, in general, expressed by the term "ampere-turns." While the product C N has a constant value, the magnetomotive force remains constant, no matter how the respective values of C and N may vary.

The space surrounding a magnet wherein lines of force exist is termed the magnetic field of the magnet. This expression, however, is sometimes restricted when speaking of a dynamo, and refers only to the space between the two poles.

If a magnet is bent so that its poles come directly opposite one another, with their faces parallel, it may be assumed the lines of force distribute themselves uniformly over the pole-faces. This corresponds to the conception of a homogeneous magnetic field (Fig. 10). (For the study of questions connected with lines of force, see the work of H. Ebert, "Lines of Force.")

The field of a dynamo is homogeneous only so long as the armature is open-circuited, and provided the poles are bored concentric to the armature.

B. Phenomena of Induction.

1. *Generation of E.M.F.'s and of Currents.*

If we place a wire within a tube made from metal of high conductivity, connecting the two free ends of the wire to the terminals of a galvanometer (Fig. 2), on sending a current through the tube lines of force will be generated encircling both that and the conductor within it. At the

instant the lines of force come into existence, a deflection of the galvanometer is observed. The current which produces this deflection endures only for the time during which the strength of the current in the tube varies, so producing an alteration in the number of lines of force generated. Calling the current along the tube the magnetising current, if this is kept constant during an appreciable time, then the induced current ceases. Any change in the magnetising current produces a corresponding change in the number of lines of force, and thence an induced current; this current is indicated by the galvanometer. Increase of magnetising current means increase in the number of lines, and the more quickly these lines increase in number the greater will be the strength of the induced current.

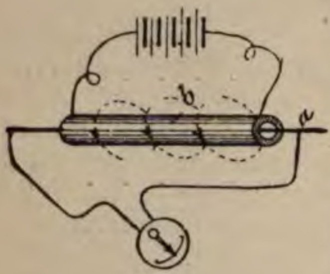

FIG. 2.

In general, the E.M.F., e, induced in the secondary circuit at any instant will be given by the equation

$$e = \frac{d\,\phi}{d\,t} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

When the number of lines of force passing through a circuit either increases or decreases in a regular manner, so that we may consider the rate of increase or decrease as constant over a small interval of time, $\Delta\, t$, the induced E.M.F. may be easily determined if we know the number of lines,

$$\phi_0,\ \phi_1,\ \phi_2,\ \phi_3,\ \text{etc.},$$

corresponding to the times,

$$0,\ \Delta\, t,\ 2\,\Delta\, t,\ 3\,\Delta\, t,\ \text{etc.}$$

Thus we shall have

$$e_0 = \frac{\phi_1 - \phi_0}{\Delta\, t}\ ;\quad e_1 = \frac{\phi_2 - \phi_1}{2\,\Delta\, t},\ \text{etc.}$$

Similar phenomena of induction result when a conducting circuit is moved about in a stationary but irregular magnetic

field, since the number of lines of force enclosed by the circuit will vary from moment to moment. The formulæ already given will obviously apply to this case also, since their validity in no way depends on the manner in which the modification of the number of lines of force passing through the circuit is produced. The actual value of the E.M.F. at any instant may be easily calculated as follows: Instead of considering the circuit as a whole, let us suppose it to consist of two separate wires, and determine in what manner the variation of the total number of lines included in the circuit is related to the rate at which the lines are being *cut* by the separate conductors.

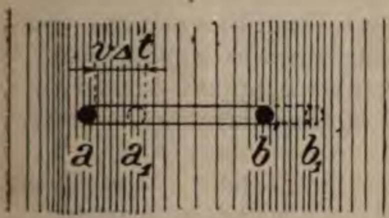

FIG. 3.

Let us suppose, for example, that a conducting circuit is moved in the field, of which a section is sketched in Fig. 3, with a velocity of v centimetres per second.

Let l be the length of either wire, perpendicular to the plane of the paper, whilst B and B_1 denote the density of the lines (per square centimetre) at the positions a and b respectively.

Taking Δt sufficiently small, we might consider the density of the lines to be practically constant for points between a and a_1 (where $a\,a_1 = v\,\Delta\,t$), and similarly for b and b_1.

The number of lines of force included by the circuit will therefore, during the interval Δt, be increased by

$$v\,\Delta\,t\,l\,B,$$

and decreased, during the same interval, by

$$v\,\Delta\,t\,l\,B_1.$$

Consequently, the effective variation will be given by

$$v\,\Delta\,t\,l\,(B - B_1),$$

which, in its turn, corresponds to an E.M.F. of

$$e = \frac{v\,\Delta\,t\,l\,(B - B_1)}{\Delta\,t} = v\,l\,(B - B_1). \quad . \quad . \quad (6)$$

The equation (6) shows also in what manner the induced E.M.F. may be calculated when a single conductor is moved about in a magnetic field. In this case we may take $B_1 = 0$, whence

$$e = v\, l\, B \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

When a circuit comprises a certain number, N, of turns, the above results must be multiplied by N. The E.M.F. may be converted into volts by dividing by 10^8 (see p. 17).

We have avoided, up to the present, making any mention of the strength of the induced current. It may be easily seen that under certain circumstances the induced E.M.F. might exist without being accompanied by any current, just as water may be subjected to a hydrostatic pressure without any flow resulting.

If we connect the two ends of the movable conductor by means of a second conductor, which latter, however, is beyond the inductive influence of the lines of force, in the circuit thus formed we shall obtain a current, the strength, C, of which is directly proportional to the pressure E, and inversely proportional to R, the sum of the resistances offered by the completed circuit:

$$C = \frac{E}{R} \text{ (Ohm's law)} \quad . \quad . \quad . \quad (8)$$

The work done during the passage of this current for one second is given by the formula:

$$C\, E = C^2\, R = \frac{E^2}{R} \text{(Joule's law)} \quad . \quad . \quad (9)$$

Multiplying both sides of equation (7) by C, we get on the left hand an expression equivalent to the electric work done in unit time, and on the right the product of a quantity v (which represents the length of path traversed in unit time by the conductor), into $C\, l\, B$, which latter, therefore, represents the force acting on the conductor.

The direction of the induced current is easily ascertained by using Faraday's rule:

"If one imagines himself in a magnetic field so that the lines of force enter at the feet and issue at the head, when looking in the direction of the movement the flow of the induced current will always be from left to right."

The positive direction along a line of force is universally defined as that in which a N magnetic pole would move if placed in the field. Consequently, a magnetic needle when placed in a magnetic field will set itself with its N pole pointing along the positive direction of the lines of force at the place where it is situated.

Increasing Flux. Decreasing Flux.

FIG. 4.

If we accept the convention that the generation of lines of force round a conductor produces an E.M.F. in that conductor, we get a simple rule for the direction of current flow: *Looking towards a coil in the positive direction along the lines of force, then, if the number of lines of force enclosed by the coil is diminishing, the current in the coil will have the direction of the hands of a watch* (Fig. 4).

When a single wire is considered, we can always suppose that it forms part of a closed circuit, and the above method may be followed.

2. *Dynamo-Electric Machines.*

After having in the preceding pages treated of the most important laws relating to electromagnetic phenomena, we shall now occupy ourselves with some details relating to the methods by which such phenomena may be utilised for industrial purposes.

The fact that the construction of dynamos preceded by some score of years a correct theory of their working has acted prejudicially to their development, since each step that has been made toward better construction has cost much time and labour, and often the results of experiments have been misunderstood owing to the ignorance which reigned in regard to fundamental principles. It would be most interesting to follow the steps by which the state of perfection obtaining at the present day has been reached; but the limits prescribed for this work would not permit us to enter into the details

of such a history. We will therefore at once devote ourselves to the study of the continuous-current dynamo as it at present exists.

However different continuous-current dynamos may be in their forms, their windings, and their modes of construction, they all possess the following features in common—viz., a stationary magnetic field, together with an armature and commutator which revolve.

An E.M.F. is produced in the armature windings by the variation in the number of lines of force threading the circuit at any instant. All attempts hitherto made to use a fixed armature and to revolve the field magnets, have miscarried on account of the other complications which were thus introduced.

We must first of all examine how the laws of induction already given may be applied to a circuit *turning* in a magnetic field.

In Fig. 5, N S represents the magnetic field, A the armature which revolves, and on which we may suppose for the moment that a single turn is wound. The armature consists of a ring composed of insulated discs of iron. We shall see later the importance of this insulation of the iron discs. Since iron offers to the passage of lines of force a resistance very much smaller than that of air, nearly all the lines leaving the N pole will traverse the iron of the armature. Let us consider the distribution of these lines over the surface of the armature; we shall find that the greatest density of lines occurs between the polar surfaces and the armature core. This is due to the fact that in this situation the distance traversed by the lines in air is a minimum. Further, the field between the pole-pieces and the armature core is homogeneous. On the other hand, outside the angles of the

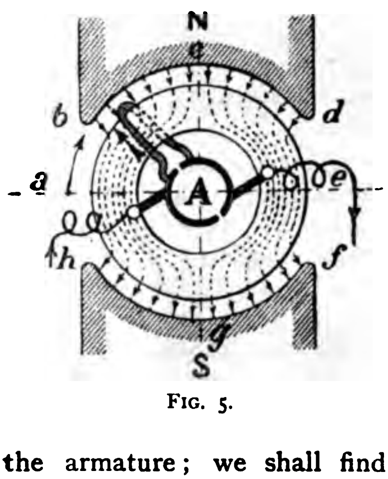

FIG. 5.

pole-pieces, b, d, f, h, the density of the lines decreases very rapidly, and becomes equal to zero at the neutral line, a, e.

Let B represent the density of the lines of force at any point on the periphery of the armature.

When the armature, together with its windings, is set in motion, the induction through the coil is constantly modified. Consequently an E.M.F. is induced in the coil, its instantaneous value being given by equation (7)—viz.:

$$e = \frac{v\,l\,\mathrm{B}}{10^8}.$$

In the present case

$$v = \frac{\mathrm{D}\,\pi\,n}{60},$$

where D is the diameter of the armature in centimetres, and n is the number of revolutions per minute of the armature. We may further remark that when the armature revolves in the sense indicated, the induction through the coil increases from g to a and from c to e, whilst it decreases from a to c and from e to g. But whilst in passing through the points a and e the direction in which the lines of force pass through the circuit remains unaltered, this direction changes on passing through the points c and g. Consequently, during a complete rotation, the induced current will twice change in direction—viz., at the points a and e.

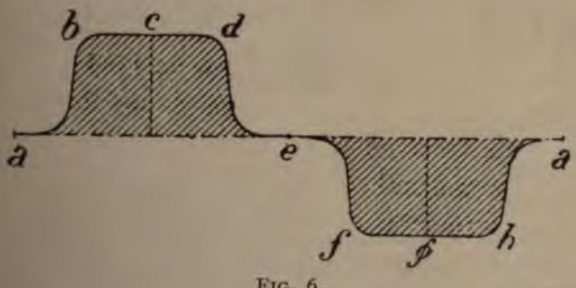

FIG. 6.

When the E.M.F. for different positions of the armature are plotted on a diagram, a curve similar to Fig. 6 is obtained.

In order to transform the resulting *alternating current* into a current always flowing in the same direction, or a *continuous current*, *Pixii* made use in 1832 of a *commutator*, which has since been greatly improved.

The most simple form for a commutator* consists essentially of two contact-pieces, turning with the armature, and connected respectively with the extremities of the coil; the current is carried away by means of two fixed brushes. The position of these brushes should be such that they pass from one contact-piece to the other at the moment when the current is reversed (Fig. 5). In the arrangement shown in Fig. 5 the coil cuts only half the lines of force leaving a field-magnet pole. But the coil may equally well be wound around the entire armature, as is suggested by Fig. 7.

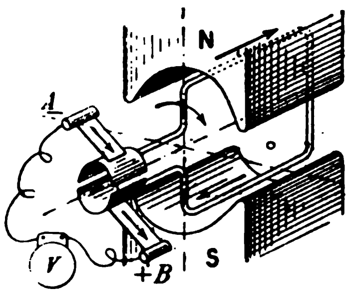

FIG. 7.

The arrangement shown in Fig. 5 has received the name of a *ring winding*, whilst one similar to Fig. 7 is called a *drum winding*.

It may be remarked, in passing, that in the case of a drum winding the brushes will generally occupy a position different from that appertaining to a ring winding. This rule, however is not absolute, since we may easily turn the commutator through a right angle with respect to the armature windings.

Commutators with only two contact-pieces, or *sections*, are now seldom employed except in the case of very small machines, and then chiefly in those furnished with the H armature originally due to Siemens. The use of this type of commutator entails the grave inconvenience that the electrical pressure, and with it the resulting current, varies considerably during a revolution, and even becomes equal to zero during a small interval of time. We might obviate this inconvenience by providing the armature with several

* The term "collector" is sometimes applied to a commutator. In England however, the term collector is restricted to *ring contacts*

coils, and the commutator with several sections; connections should be established in such a manner that a number of coils, possessing different instantaneous E.M.F.'s, are grouped in series.

The principal windings of this sort are described in Chapter II. All present this peculiarity—that they form one or more closed geometrical figures. They are therefore called *closed windings*. Another characteristic property of these windings is that the brushes serve to connect two circuits in parallel. We shall have occasion to speak of *open windings*, in which all the armature coils are grouped in series, when we come to speak of dynamos for arc lighting; such arrangements are used for no other purpose.

As is shown in the pressure curve (Fig. 8) the current cannot be rendered constant by the use of four commutator sections; the pressure in this case varies between E and $\sqrt{2}$. E. By increasing the number of commutator sections, this irregularity is diminished.

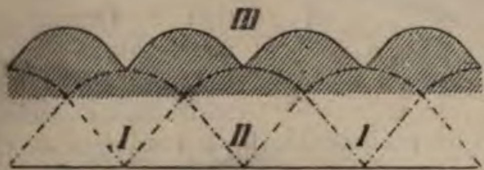

FIG. 8.

If the terminal pressure be taken as the sum of the pressures for an entire revolution of a single coil, we can, without much difficulty, estimate the amplitude of the undulations which the current will undergo.

We say "estimate"; for, in fact, an exact calculation is impossible, due to a circumstance which will be more fully considered subsequently. Owing to the mutual action exerted between a current and its magnetic field, the variable magnetic field in the armature which results from the undulating current produces in the windings an E.M.F. which opposes either an increase or decrease of the current.

It is due to this circumstance that the current may be considered as constant, even when the number of commutator sections does not exceed 16 or 20.

To obtain the general formula for pressure, let us examine Fig. 9.

Let the armature turn in a given direction with velocity

$$v = \frac{D \pi n}{60} \text{ centimetres.}$$

The conductors between A and B will not be cutting any lines of force, except the small number due to magnetic leakage. Consequently the pressure generated in these conductors will be zero, or, at least, for our present purpose, negligibly small. It is different, however, with the wires under the poles. These are moving through a distance of v centimetres per second; hence it follows that a decrease or increase equal to $v\,B\,l$ per second will occur in the number of lines surrounding each conductor, according to its position to the left or right of C.

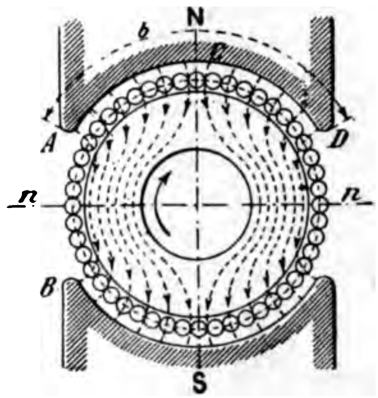

FIG. 9.

Until C is reached the number of lines of force decreases, but after that point is passed increase takes place. The direction of the current, however, is unchanged, inasmuch as the direction of the lines of force is reversed.

The E.M.F., or pressure, in each wire is

$$e = v\,B\,l,$$

and as the entire number of wires at any instant under the action of the field is equal to

$$\frac{2p \cdot b}{D \pi} N,$$

where p = number of pairs of poles, and the meaning of b is denoted in Fig. 9, it follows that the total pressure,

$$E = v\,B\,l \frac{2pb}{D\pi} N = \frac{2n \,.\, B\,l\,b \,.\, N}{60}$$

and the pressure in volts is obtained by dividing this expression by 10^8.

A slight modification of this formula is needed when it is applied to ordinary direct-current machines: Firstly, $B\,l\,b$ (or the total number of lines issuing from one pole) may be represented by ϕ. Then it follows, as will be shown later on, from the nature of direct-current windings, that there are as many points of collection of current as there are parallel circuits in the armature.

If p_1 = the number of circuits each consisting of two branches in parallel (p_1 = half the number of collecting points), then the pressure between two brushes, or collecting points, is $\left(\frac{1}{2\,p_1}\right)$ of the pressure represented in the above formula.

We thus obtain the important equation—

$$E = \frac{n\,\phi\,N}{60\,.\,10^8}\,.\,\frac{p}{p_1}\text{ volts} \quad . \quad . \quad . \quad . \quad (10)$$

E is the internal (or total) pressure, or the E.M.F. The external pressure—that is, the pressure between the brushes—= the internal pressure, less the drop of pressure in the armature.

The above formula is equally applicable to drum and ring armatures, inasmuch as N represents only the number of conductors on the circumference of the armature.

It still remains for us to say a few words concerning the second of the principal organs of a continuous-current dynamo—viz., the field-magnet system.

The merit of having first utilised the continuous current supplied by the armature for the purpose of exciting the field magnets must be ascribed to MM. Brett and Sinsteden; their discoveries were dated 1848 and 1851. But as these arrived too soon, these first attempts had been completely forgotten when Werner Siemens and Wheatstone arrived at the same idea (*Proceedings*, Royal Society, February 14, 1867). Siemens proposed to conduct the whole of the current round the magnets, whilst Wheatstone only utilised a part of it. In this manner *series* and *shunt wound dynamos* had their origin; *compound-wound* machines were invented

later by Brush, in which both the above methods of excitation were simultaneously employed. As we shall return to the subject in a later chapter, a detailed description will not be given here.

We will confine ourselves for the present to the following preliminary indications:

As in a series dynamo the whole of the current circulates round the field magnets, every alteration in the resistance of the external circuit of the machine will produce a modification of the current, and hence an increase or reduction of the terminal pressure. On the contrary, in shunt-wound machines the field magnets are connected in parallel with the external circuit. The exciting current is therefore hardly influenced by the resistance of the external circuit. Shunt-wound machines, therefore, work with a constant excitation, and hence an induced E.M.F., which is also practically constant. This end is, however, more completely attained by compound-wound machines.

3. *Motors.*

Up to the present our remarks have been confined to the phenomena attending the induction of currents. We now suppose that the conductor, instead of moving in the magnetic field, is kept stationary. If we connect the two ends with some external current-generating source at a given pressure, e, there will flow through the circuit so formed a current of the maximum strength

$$C = \frac{e}{R},$$

where R is the total resistance of the conductor and connections—that is, of the circuit.

Further, a force

$$F = C\,l\,B \text{ ergs} = \frac{C\,l\,B}{9{\cdot}81 \times 10^6} \text{ kilogrammes*} \quad . \quad (11)$$

is exerted upon the conductor, tending to move it in a direction at right angles to the field. The direction of this

* For the relation between absolute and practical units, see table p. 17.

movement will be exactly opposite to that which would have to be given to the conductor when acting as a generator in order to generate a current in the same direction as that flowing from the external source.

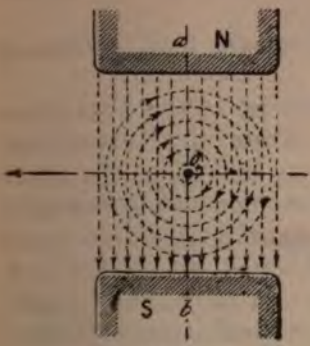

FIG. 10.

This phenomenon may be simply explained.

In Fig. 10, let O represent the conductor through which a current is flowing, its position being vertical to the plane of the paper. If the direction of current flow be towards the paper, lines of force are generated by it which circle round the conductor in the direction of the hands of a watch. An increased density of the lines occurs to the right of *a b*, and a decrease to the left of *a b*, whereby the wire is impelled towards the left.

The velocity of the movement is an increasing one, ultimately approximating to the value

$$v = \frac{e}{l\,B} 10^8.$$

Assuming that no mechanical resistance apart from friction is opposed to the free movement of the conductor, when the above velocity is obtained the current flow in the wire becomes exceedingly small, although neither the pressure nor the resistance of the circuit have been varied. This arises from the fact that the conductor, during its motion through the field, has an E.M.F. generated in it exactly as if it acted as a generator. According to the law just stated, this so-called back E.M.F., e_1, induced in the conductor is directly opposed to the impressed E.M.F., e. It consequently follows that the resultant pressure, $e - e_1$, decreases as the velocity of the conductor increases.

At any given moment the current flow is expressed by the equation

$$C = \frac{1}{R}\left(e - \frac{v \,.\, l \,.\, B}{10^8}\right) \quad . \quad . \quad . \quad . \quad . \quad (12)$$

where v = velocity.

Further, $$v = \frac{e - C\,R}{l\,B} 10^8 \quad . \quad . \quad . \quad . \quad . \quad . \qquad (13)$$

The direction of movement is given by the following simple rule:

Consider oneself placed in the magnetic field, looking in the direction of the current flow in the conductor, the lines of force entering at the feet and issuing at the head; then the outstretched right arm will indicate the direction of motion.

Equation (10) may also be adapted for determining the speed of motors:

$$n = \frac{E_1 \, . \, 60 \, . \, 10^8}{N\,\phi} \, . \, \frac{p_1}{p},$$

where E_1 = the impressed E.M.F. - C R (compare equation 13).

The interpretation of this shows that the greater the pressure between the brushes of the motor, the greater will be its number of revolutions, and *vice versâ*. The number of revolutions may be diminished by strengthening the magnetic field and increased by weakening it. Both methods are utilised for regulating the speed of motors.

The calculations required in designing continuous-current dynamos may also be as simply explained. The importance of equation (10) calls for particular attention. Without entering into too much detail, it will be well to sketch the method of procedure with such calculations. We may in the first place assume a definite air saturation, B, and further insert into our calculation—as a fractional part of the as yet unknown armature circumference—the arc, *b*, embraced by one of the pole-pieces:

$$b = \beta \frac{D\,\pi}{2\,p}.$$

The diameter, *d*, of the wire depends upon the current, *C*, to be carried, and this again depends upon the permissible current, *c*, per square millimetre.

The number of turns per centimetre circumference which can be placed upon the core of the particular type of armature (smooth, slotted, or toothed) selected is fixed, so that

$$N = k_1 \, . \, D\,\pi;$$

it is assumed that the armature length $e = \lambda\,D$.

Equation (5) may then be written

$$E = \frac{n \, . \, B \, . \, \beta \, D \, \pi \, \lambda \, D \, . \, k_1 \, . \, D \, \pi}{2 \, . \, p \, . \, 60 \, . \, 10^8} \, . \, \frac{p}{p_1}$$

$$= \frac{n \, B \, . \, \beta \, \lambda \, k_1 \, . \, \pi^2 \, . \, D^3}{2 \, . \, 60 \, . \, 10^8 \, . \, p_1},$$

and

$$D = \sqrt[3]{\frac{E \, . \, p_1 \, 2 \, . \, 60 \, . \, 10^8}{n \, B \, . \, \beta \, \lambda \, . \, k_1 \, . \, \pi^2}}.$$

For practical use more convenient formulæ will be given later.

In the above equation, E and n are known quantities: p_1, B, $\beta \lambda$ and k_1 are factors which can be determined by choice, the calculation of D thus becoming simple.

The armature dimensions being known, the calculations for the magnet can be proceeded with. The magnet must be so proportioned that the specified number of lines, ϕ, per pole is obtained.

The calculations for continuous-current dynamos are thus reduced to the following consecutive operations: (*a*) design of the armature with a definite ϕ as base for calculation: (*b*) design of the magnet for obtaining this induction.

C. Units of Measurement—Calculation of Resistance.

For the benefit of those readers not well acquainted with the fundamental laws of electricity, we shall briefly refer to those necessary to the due understanding of this book.

If we measure the values of current and pressure in so-called absolute units (C.G.S. units) and obtain their product, we get the amount of work done in ergs. Absolute units are, however, unsuitable for practical calculations because of their smallness, hence units of higher values, called practical units, have been introduced.

Practical unit of current	1 ampere (A)	10^{-1} absolute units.
,, ,, pressure	1 volt (V)	10^8 ,, ,,
,, ,, resistance	1 ohm (ω)*	10^9 ,, ,,
,, (electrical) power	1 volt × ampere = watt (V A)	10^7 ,, ergs
,, (mechanical) ,,	1 kilogrammetre per second	$9{\cdot}81 \times 10^7$
,, unit of power	1 horse-power	746×10^7

* Even this unit is too small for calculations of insulation resistance, and it is usual to use the megohm, a million times greater, or 10^{15} absolute units in such measurements.

From the above table it follows that

$$1 \text{ watt} = \tfrac{1}{746} \text{ horse-power},$$

or,

$$746 \text{ watts} = 1 \text{ horse-power}.$$

The absolute unit of force, called the dyne, *is that force which produces an acceleration of* 1 *centimetre per second on the mass of* 1 *gramme.*

$$1 \text{ gramme} = 981 \text{ dynes}.$$
$$1 \text{ kilogramme} = 981{,}000 \text{ dynes}.$$

Inasmuch as the practical unit of current is ten times greater than the absolute unit, the expression to obtain the value of a force in kilogrammes is

$$F = \frac{B\,l\,C}{9{\cdot}81 \times 10^6} \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

where C is measured in amperes.

As an illustration, suppose the force generated in a single armature wire is to be calculated. Let the wire move in a magnetic field possessing a density of 6,000 lines per square centimetre, and let the current through the wire be 100 amperes, with a length of armature 50 centimetres; then

$$F = \frac{6{,}000 \times 50 \times 100}{9{\cdot}81 \times 10^6} = 3{\cdot}06 \text{ kilogrammes}.$$

Thus we see as the sectional area of the wire increases, so does the current generated in it, and due provision must therefore be made to secure it against displacement.

The resistance of a conductor is calculated from the formula

$$R = \frac{L}{S} \cdot \rho \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$

where L is the length in metres;

S is the sectional area in square millimetres;

ρ is the specific resistance $= \dfrac{1}{\text{specific conductivity}}$.

Table I. (at the end of the book) gives the specific resistance for different conductors at freezing point.

The resistance of most solid conductors increases with increase of temperature, but at a varying rate with different

materials. Carbon, however, is an exception to this rule. Taking the resistance coefficient at 0° as a basis, we can easily calculate the resistance at any temperature $t°$:

$$\rho' = \rho^{\circ} (1 + \sigma t) \quad . \quad . \quad . \quad . \quad . \quad (16)$$

(See Table I. at end of book.)

The rise of temperature is sometimes considerable, so that in calculations it is well to make the necessary allowance for this, especially when many contiguous wires are in question.

An example may be considered:

Suppose the temperature of the magnet coil to rise to 60° C., which is indeed quite normal, then:

$$\rho^{t} = \rho^{\circ} (1 + 60 \times 0{\cdot}0037) = 1{\cdot}22\, \rho^{\circ}$$

that is, the resistance of the magnet coil is increased 22 per cent., or, what amounts to the same thing, the exciting current is decreased in that proportion.

When a number of resistances, r_1, r_2, r_3, etc., are connected in series, the total resistance is the sum of their respective resistances, or,

$$R = r_1 + r_2 + r_3 + \quad . \quad . \quad . \quad r_n \quad . \quad . \quad . \quad (17)$$

When the ends of the several resistances are bunched together (parallel arrangement), the total conductive capacity —*i.e.*, the reciprocal of the total resistance—is equal to the sum of the reciprocals of the individual resistances, or of the individual conductivities. Thus—

$$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \frac{1}{r_4} \quad . \quad . \quad . \quad . \quad (18)$$

and $$R = \frac{r_1\, r_2\, r_3\, r_4}{r_2\, r_3\, r_4 + r_1\, r_3\, r_4 + r_1\, r_2\, r_4 + r_1\, r_2\, r_3} \quad . \quad . \quad (19)$$

CHAPTER II.

Armature Calculations.

A. Methods of Winding.

In the following pages we shall consider, as far as space permits, those methods of closed coil winding generally in use. For other windings the reader should consult the work of Prof. E. Arnold ("Die Ankerwicklungen und Ankerkonstructionen der Gleichstrom - Dynamomaschinen," second edition, 1896. Berlin and Munich.)

1. *Ring Winding.*

Fig. 11 represents the Pacinotti-Gramme ring. As indicated in the diagram, a current in one direction flows through all the turns of the wire situated above the neutral line, *n n*, while a similar current flows in an opposite sense through the turns below *n n*. If lines of force go through the air-space enclosed by the armature, an E.M.F. will be generated in the connecting wires lying upon the inner surface of its core, which is an opposing E.M.F. to that generated in the outer wires, and which will, to say the least, diminish the effective E.M.F. of the machine. The air-space, however, offers a much greater resistance to the passages of these lines than does the iron armature core; hence, with proper precautions, this detrimental effect may be reduced to an almost negligible quantity.

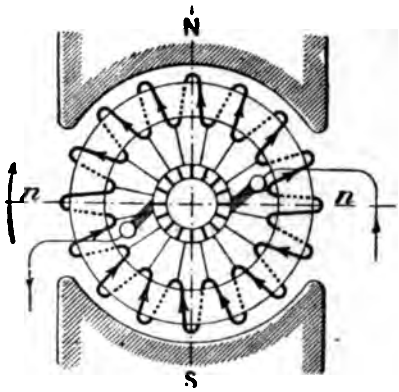

Fig. 11.

In the following operations we will denote by—

e, the pressure generated in one armature element or section—that is, the coil between two commutator segments. For simplicity, we assume that all the conductors on the outside of the armature, including those which at any instant are outside the poles, are equally influenced, whereby a small error is involved in the determination of e_1 and e_2.

e_1 is the maximum difference of pressure between two sections of the armature winding.

e_2 is the maximum difference of pressure between two commutator segments.

N_1 is the number of armature sections; in the Gramme winding this is equal to the number of commutator sections.

N_2 is the number of commutator sections.

$2\ p_1$ is the number of parallel circuits, generally equal to the number of lines of brushes or collecting points.

For a two-pole dynamo $p_1 = 1$.

For a four-pole machine with two points of collection also $p_1 = 1$.

For a four-pole machine with four collecting points $p_1 = 2$, and so on.

In calculations relating to windings, the following are important details:

Maximum pressure, e_1, between adjacent coils or wires.

Maximum pressure, e_2, between two contiguous commutator sections.

Maximum possible number of commutator segments (N_2).

Number of armature turns simultaneously short-circuited by a brush.

With respect to Fig. 11,

$$N_2 = N_1;$$

$$e_1 = 0;$$

$$e_2 = \frac{2\ E}{N_2} = \frac{2\ E}{N_1}.$$

The number of armature turns simultaneously short-circuited $= 1$.

The number of turns in series between brushes is seven and eight alternately. If the whole of these turns were simultaneously under the influence of the poles, the result would be a variation of about 12 per cent. in the pressure. However, the short-circuited coils lie in the neutral zone where the induced pressure is practically nil, so that the actual variation is considerably less, and, indeed, is negligible with about 20 commutator sections.

With the multipolar ring armatures (Fig. 12) there are as many pairs of circuits in parallel as there are poles. Hence,

$$p_1 = p;$$
$$N_2 = N_1;$$
$$e_1 = 0;$$
$$e_2 = \frac{2\,p_1\,E}{N_2} = \frac{2\,p_1\,E}{N_2}.$$

The current in one armature conductor is equal to the total current divided by $2\,p_1$.

Windings requiring more than two brushes for collecting are sometimes called "parallel windings," to distinguish from series windings.

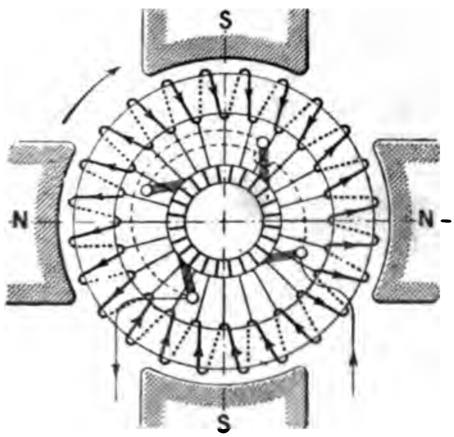

FIG. 12.

It is often desirable with multipolar ring windings to reduce the number of collecting points, which, as suggested by Mordey, may be done by cross-connecting opposite commutator bars (Fig. 13). In such cases the size of the commutator must be doubled, and another necessity is that N_2 must be an even number.

The arrangement can also be applied to dynamos with more than two sets of brushes. It possesses the advantage

that small differences of pressure between individual sections are adjusted, and it allows of the brushes mounted upon any one arm being lifted while the machine s running.

The angular distance in degrees between any two points of collection is always

$$a = \frac{360}{2p},$$

and the brushes are placed between two poles.

An examination of Fig. 13 shows that in this way two sections, as a and a_1, b and b_1, are in parallel.

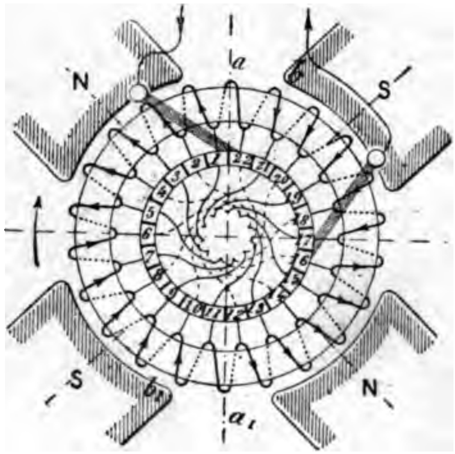

FIG. 13.

Thus, without interfering with the ultimate pressure of the machine, we can suppress alternate turns, doubling the E.M.F. of the remaining sections. By this method we have the extremely interesting winding shown in Fig. 14, which lends itself to the construction of high-pressure machines. At Oerlikon all traction motors have been wound in this way since 1892.

A noticeable feature in this method of winding is that

$$N_2 = 2\ N_1.$$

To allow of this method of winding, $\frac{N_2}{2} = N_1$ must be an uneven number:

$$e_1 = \frac{2\ E}{N_1};$$

$$e_2 = \frac{2\ p\ E}{N_2} = e_1.$$

The same arrangement is suitable for six-pole machines, though the commutator connections are somewhat complicated.

Fig. 15 represents another method of series ring winding due to Prof. Perry (1882) applied to a four-pole machine, and which can be adapted to machines irrespective of the number of poles.

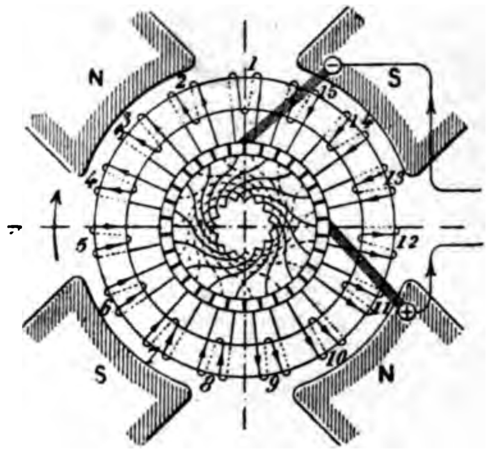

FIG. 14.

Neither here nor later will we attempt to distinguish between methods of winding, differing only in the relative positions of the coils and the commutator segments with which they are connected. Imagine, for instance, that the connecting wires between the coils and their respective commutator bars in Fig. 15 consist of flexible cable, then we may without difficulty move the commutator through 45° either forwards or backward relative to the armature, the brushes being brought under these conditions directly below the poles. We might avail ourselves of this alternative when the brushes in their natural position are inconveniently placed.

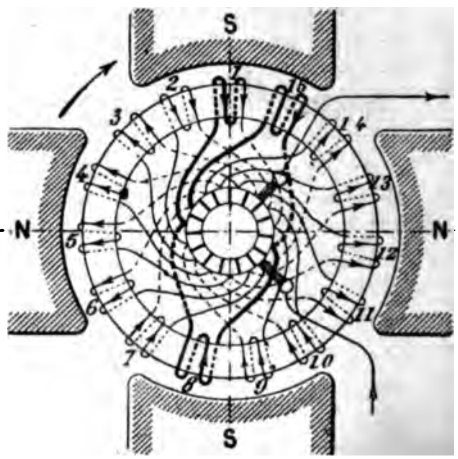

FIG. 15.

The spacing* or pitch of the winding is for any number of poles:

* The name *spacing* or *pitch* is applied to the distance whic elements connected together, or to the number of sections (eith conductors) which separates them.

$$y = \frac{N_1 \pm 1}{p} \quad \ldots\ldots\ldots \quad (20)$$

Should p be even, then N_1 must be uneven; while if p be uneven, either case is possible.

$$N_2 = N_1;$$

$$e_1 = \frac{2\,E}{N_1}(p + 1);$$

$$e_2 = \frac{E}{N_2} \cdot 2p = \frac{E \cdot 2p}{N_1};$$

$$p_1 = 1;$$

$$a = \frac{360}{2p}.$$

This arrangement is always used where the natural position of the brushes renders them accessible.

In Fig. 15 the normal position for the brushes is between the poles.

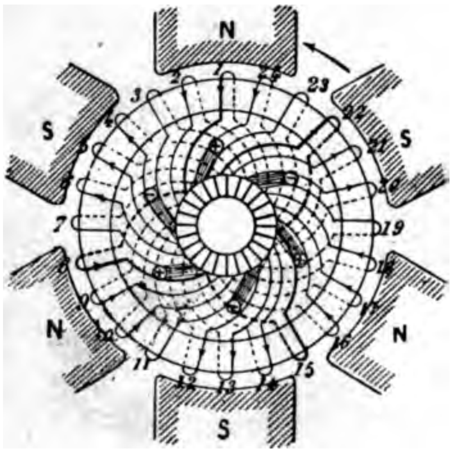

FIG. 16.

In very large parallel-wound dynamos, it is practically impossible, owing to various trifling faults, constructional or otherwise, such as eccentric borings, casting imperfections, flaws, etc., to avoid small pressure differences between the sections. Detrimental influence from these causes may be rectified in the ring method of winding by the method suggested by Prof. E. Arnold, shown in Fig. 16, whereby the coils connected between any two brushes are under the influence of all the poles.

...ing formula for any number of poles is:

$$y = \frac{N_1 \pm p_1}{p} \quad \ldots\ldots\ldots \quad (21)$$

(In Fig. 16, for example, $N_1 = 24$; $p = p_1 = 3$; $y = \frac{24-3}{3} = 7$).

In order to diminish the current flow through short-circuited coils, the armature may be provided with two separate windings (Fig. 17). In this case, the brushes should never bridge less than two commutator segments, otherwise, in certain positions of the armature, one of the windings would be entirely cut out of the circuit.

A similar winding on the drum principle is dealt with in Chapter IX.

2. *Drum Windings.*

The drum method of winding was first introduced by Hefner von Alteneck, engineer to the firm of Messrs. Siemens and Halske.

Drum windings are distinguished from ring windings in that all wires in the former are distributed over the surface of the armature core. Thus, in order that the E.M.F.'s of the individual inductor may be summed up in series, the two parts of the inductor forming a single loop or section must never come simultaneously under the influence of the same pole, but must respectively be under the influence of opposite poles.

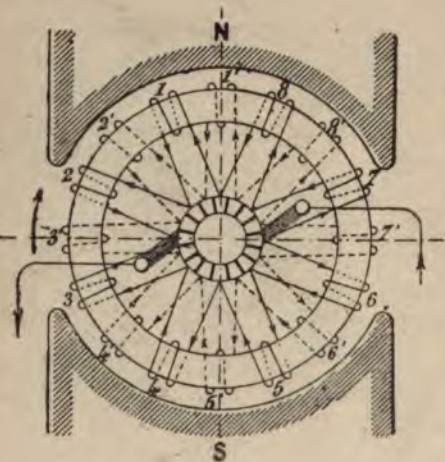

FIG. 17.

The winding may be either a "series wave winding" if in its continuation round the armature core it passes from pole to pole successively, or a "lap winding" if the winding passes from under the first or starting pole to the next, and then is brought back again, and so on; thus working forwards each time only through that distance represented by the pitch of the winding.

The distance between two successive elements of a winding is termed the "pitch of the winding."

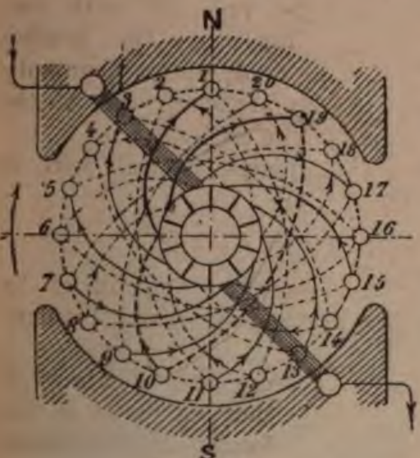

FIG. 18.

In the case of a lap winding, the pitch is alternately y and y_1; in a wave winding the pitch could remain constant i the number of elements is appropriately chosen, thus securing certain constructional advantages.

As a fundamental rule it may be stated that the pitch, either y or y_1, must always be an uneven number. The only exception is when the windings are in two layers; the pitch is then given in relation to a single layer only. The reason for the terms *wave* and *lap* winding is apparent if the armature surfaces are flattened out and the windings shown in plan as in Figs. 24 and 26. Figs. 18 to 22 show various ways of bipolar drum windings. Figs. 18, 19, 21, and 22 belong to the wave kind; Fig. 20 to lap winding. With the latter kind the two pitches, y and y_1, must at most be equal to the pole arc, b. In comparison with other windings, the latter method has the advantages that fewer wires intersect and their length is somewhat less.

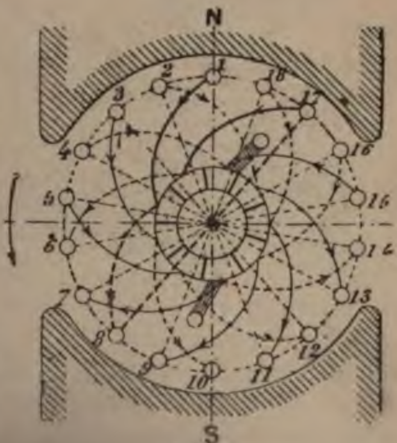

FIG. 19.

he position of the brushes Figs. 18 to 20 is in the axis connecting the poles, while Fig. 21 it is in the ne e. Owing to the latter

circumstance, preference is often given to this particular method of winding when motors with fixed brushes are in question. A disadvantage of the winding shown in Fig. 21 is that, on account of the commutator connections, it occupies rather more space.

The following are rules for wave winding (Figs. 18, 19, and 21):

$$y + y_1 = N_1 \pm 2; \quad . \quad . \quad . \quad . \quad . \quad (22)$$

(y and y_1 = uneven numbers).

$$N_2 = \frac{N_1}{2};$$

$$e_1 = E - 1;$$

$$e_2 = \frac{2E}{N_2}.$$

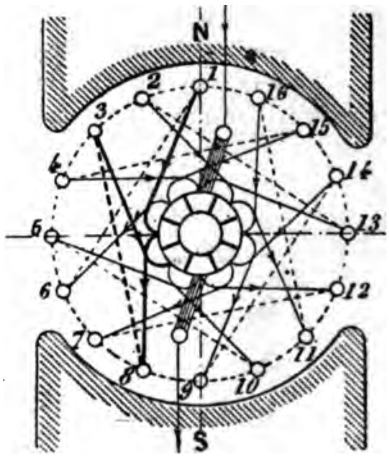

FIG. 20.

The number of short-circuited elements = 2.

(In Fig. 18, $y = y_1 = 9$; in Fig. 19, $y = 7$, $y_1 = 9$).

Slotted armatures are generally wound with two layers (Fig. 22), but the same rules might be employed if we always imagined each wire in the second layer enclosed between two of the first. It is, however, better to determine the spacings of the first layer only. In this case, the rule that y and y_1 must be uneven is not necessary, and we have simply to observe that

$$y + y_1 = N \pm 1.$$

For example, in Fig. 22—

$$y = y_1 = 7.$$

The E.M.F. in the wires of the two layers—

$$e_1 = E - 1.$$

In the lap winding, Fig. 20, the law that y and y_1 must be uneven numbers, and

$$y - y_1 = \pm 2 \quad \ldots \ldots \quad (23)$$

must be observed.

Figs. 23 and 25 represent two types of drum winding applicable to four-pole machines. More particularly, Fig. 23 is an example of wave winding, Fig. 25 of lap winding. The corresponding developments are shown in Figs. 24 and 26 respectively.

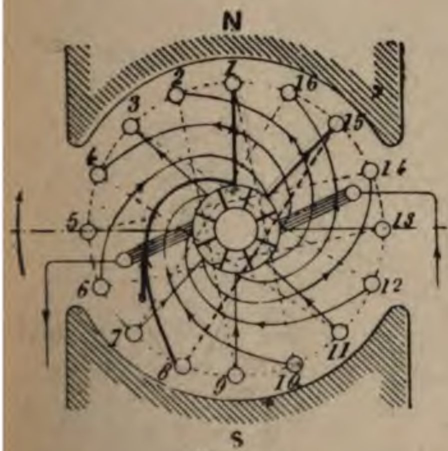

FIG. 21.

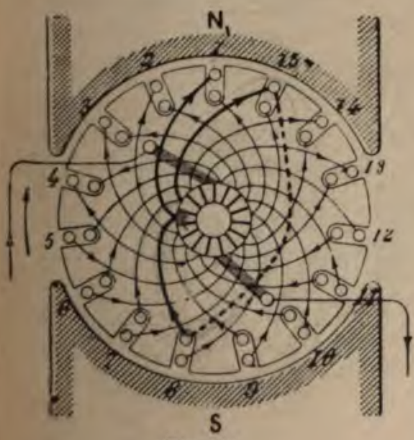

FIG. 22.

Fig. 27 shows a wave winding for a six-pole machine. Taking these examples, and tracing the current flow in individual coils, it is obvious that with wave windings only two sets of brushes are required as collectors, whilst with lap winding there are as many points of collection as there are poles. Lap windings therefore are adapted only for parallel-wound machines.

Passing to the consideration of series connected wave windings, the following relations hold both for bipolar and four-pole machines:

$$N_2 = \tfrac{1}{2} N_1.$$

When p is even, N_2 is uneven;
 ,, p is uneven, N_2 is even when $y = y_1$;
uneven when y and y_1 differ by:

$$(y + y_1) = \frac{N_1 \pm 2}{p} \quad . \quad . \quad . \quad . \quad . \quad . \quad (24)$$

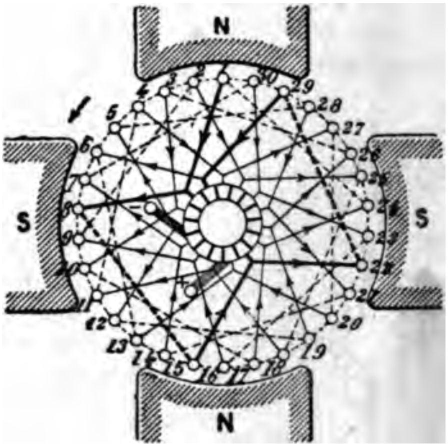

Fig. 23.

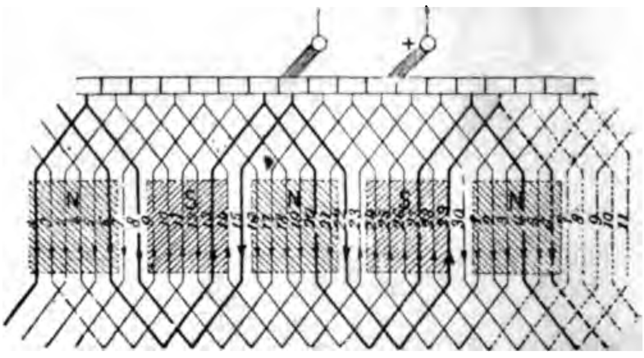

Fig. 24.

(In Fig. 23, $y = y_1 = 7$.)

$$e_1 = E - p \cdot \frac{2\,E}{N_1} = E\left(1 - \frac{2p}{N_1}\right);$$

$$e_2 = \frac{2p \cdot E}{N_2}.$$

The angle at which the brushes must be set apart is

$p =$	1	2	3	4
$\alpha =$	180°	45°	60° or 180°	45° or 135°

Further, as Prof. Arnold has pointed out, the wave method lends itself also to parallel winding. Its adaptation to a four-pole and a six-pole machine respectively is shown in Figs. 28 and 29. (Compare Fig. 16.)

The advantages mentioned in regard to Fig. 14 also belong to this winding. It is interesting to notice that the short-circuiting of a coil does not occur simultaneously with the bridging of two commutator segments, but is accomplished through two brushes of like sign. The duration of the short-circuit may therefore be adjusted as desired by simply shifting one of the two brushes, which in the case of lap windings can only be done by increasing the size of the brushes.

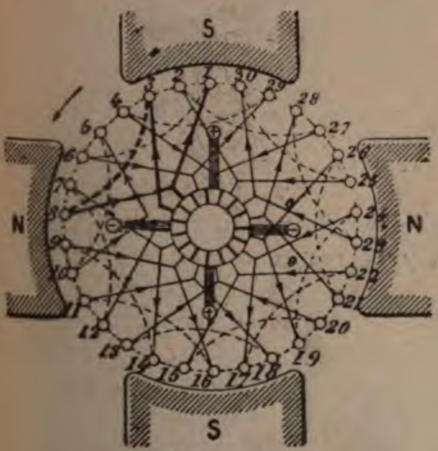

FIG. 25.

The single disadvantage of this method is, perhaps, that the intervals between the different numbers of wires for which this winding is practicable are rather great.

The following equations apply to parallel wave windings:

$$(y + y_1)\,p = N_1 \pm 2\,p_1 \quad . \quad . \quad . \quad . \quad (25)$$

In order that the winding may be practicable, the conditions necessary are $y = y_1$;

or,

$$y = y_1 \pm 2\,p_1.$$

In practice the first case only need be taken into account.

A second condition is that y and $\frac{N_1}{2}$ must not have a common divisor.

Thus, for Figs. 28 and 29: in the first,

$y = y_1 = 7$; and in the second,

$y = y_1 = 5$.

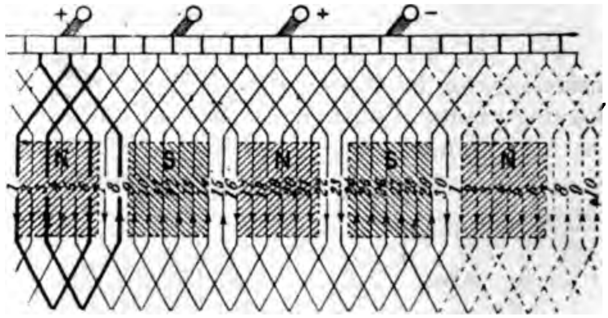

FIG. 26.

One more type of parallel winding especially suitable for high-pressure machines may be mentioned (*vide* Prof. S. P. Thompson's book). It consists of two or three separate windings, each with its own commutator, arranged in such a manner that the inductors and the commutator segments are arranged alternately. The value of this arrangement consists in that only half or a third part of the current flows through each winding, so that at the breaking of a short-circuit through the brushes only a fraction of the normal current is interrupted. Sparking at the brushes is reduced, and so is the heating of the commutator through Foucault currents. (Compare Fig. 17.)

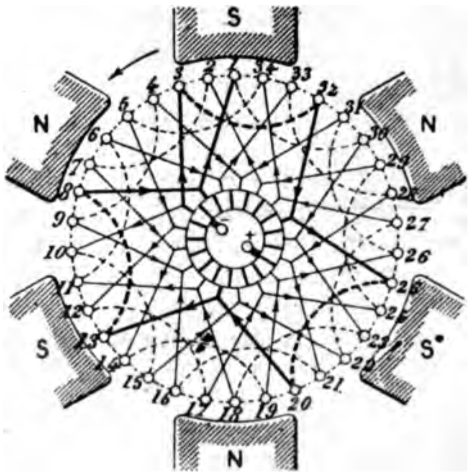

FIG. 27.

Fig. 27 shows a similar arrangement with four circuits, forming, however, a closed geometrical figure.

The fundamental equation for this winding is given by equation (25):

$$y + y_1 = \frac{N_1 \pm 2\,a}{p}.$$

Considering, for instance, Fig. 28, where $p_1 = 2$, the number of collecting points can be either four or two. In this latter case, each brush must cover at least two segments.

The condition that a closed winding should be possible is that $\frac{N_1}{2}$, $y + y_1$, and p_1 must not have a common divisor.

In Fig. 30 (taken from Prof. Arnold's book)—

$$p_1 = 4; \qquad N_1 = 50; \qquad y + y_1 = \frac{50 - (2 \times 4)}{2 \times 3} = 7.$$

Instead of extending the windings over the end faces of the core, cylinder windings, as they are called, may be used. To get an idea of these, we need only imagine the windings shown in Figs. 24 and 26 to be laid upon the surface of an armature core. Better cooling can thus be obtained, but at the expense of increased length of armature.

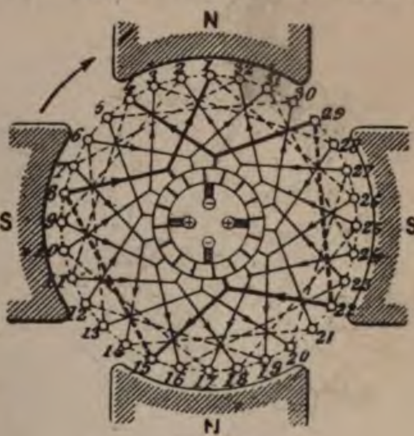

Fig. 28.

Other methods of winding may be conceived by imagining the inductors of the drum windings replaced by coils.

3. *Disc Windings.*

This type of winding is quite distinct from the flat or discoidal ring armature, in which the lines of induction enter at the sides, and not at the periphery; the opposite poles here have the same sign.

In this case the armature has an iron core built up of iron ribbon or wire, and the winding itself differs in no respect from the methods already described. The only peculiarity is in that type of disc armature in which the opposite poles are of opposite sign, the construction of which renders an iron core unnecessary. To this class belongs the Desroziers machine. The principle is shown in Fig. 31 (a form originally suggested by Sperry), with which we have already become

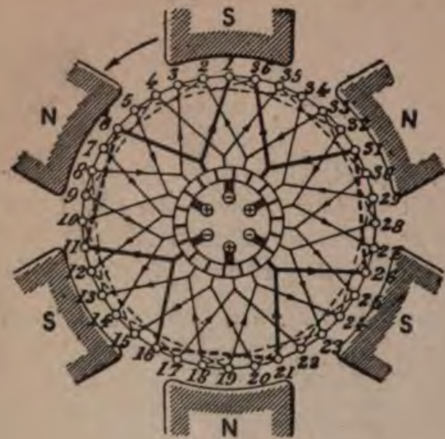

FIG. 29.

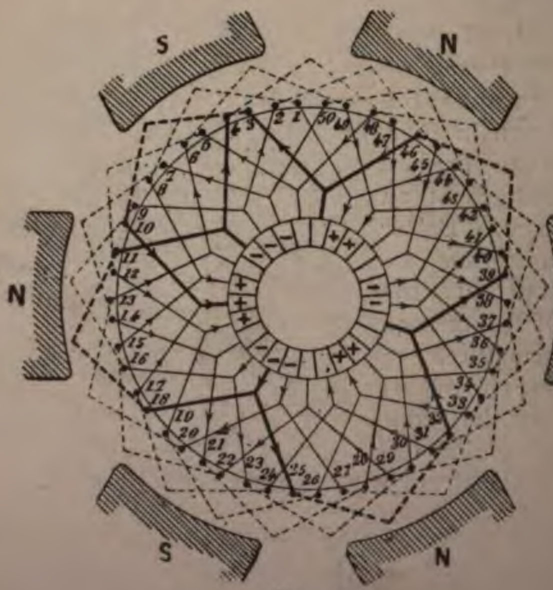

FIG. 30.

acquainted in connection with series windings. The chief peculiarity of the Desroziers armature is that the odd

inductors are separated from the even inductors, each being wound upon separate frames. Fig. 32 illustrates the method

FIG. 31.

of connections for an armature with 64 inductors. Further details of this machine will be found in Chapter IX.

The winding of the Fritsche flywheel armature is carried out on the lines of scheme 9. As, however, the peculiarity

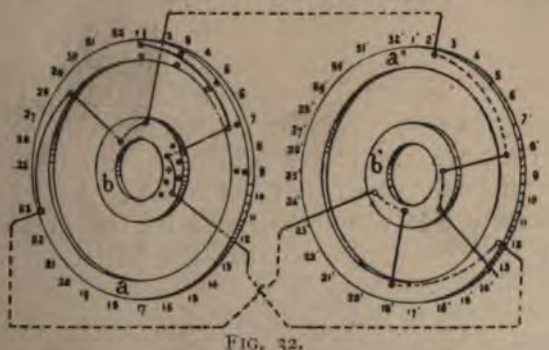

FIG. 32.

of this type of armature is in the constructional details, its discussion will be reserved till later.

4. *Comparisons Between Ring and Drum Winding.*

Armatures may be divided into the following classes according to the type of core:

(*a*) Smooth armatures (Fig. 33, arrangement *a*), in which the conductors are uniformly distributed in one or more layers over the surface of the core.

(*b*) Toothed or slotted armatures (arrangement *b*), in which the inductors are laid in grooves or notches.

(*c*) Tunnelled armatures (arrangements *c* and *d*), first employed by Wenström.

(*d*) Tunnelled armatures (arrangement *e*) in which the tunnels are not quite closed.

The latter arrangement is better than either *c* or *d* (Fig. 33), since the self-induction of a coil, when short-circuited, is somewhat diminished.

Of these various types, those belonging to the first or smooth armature type are undoubtedly the cheapest to construct as long as we only regard the core, but against this must be weighed several disadvantages. The most important is the impossibility of fully utilising the magnetic field without unduly increasing the air-gap; nor can the magnets of such machines be saturated to so high a degree as in the case of toothed armatures. Machines provided with smooth armatures are very sensitive to variations of speed. Nor must it be forgotten that the initial saving of cost in a smooth armature is counterbalanced by the greater cost of its field-magnet windings, so that the initial saving in cost is mostly illusory.

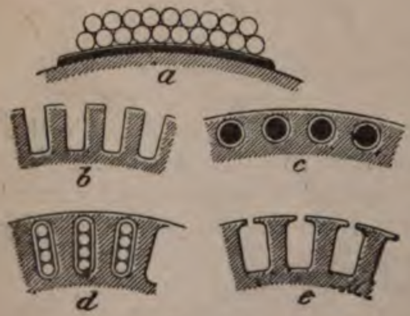

FIG. 33.

The advantages and disadvantages of ring and drum windings may be summarised:

Advantages of the Gramme Ring.—1. The pressure between two adjacent windings is nil, and thus efficient insulation is easily secured. With care, Gramme rings may be constructed to give pressures up to 2,000, and even to 3,000 volts, as is evident from the numerous successful machines built by the Oerlikon Company, the Thury Company, and others.

2. In the event of repair being required, any section can easily be replaced; further, the whole winding is easily executed.

3. Special driving horns (projecting points or wedges let into the smooth-core armature surfaces for transmitting the driving power to the wires) are not required, a natural method of transmission being provided through the radial arms of the armature hub.

4. The number of commutator segments is equal to the number of inductors, an important feature in armatures with few loops.

Disadvantages of the Gramme Ring.—1. All wires lying on the inner periphery of the core only add to the resistance, and with high degrees of saturation, lines of force penetrate and induce in these wires an opposing E.M.F.

2. Only a portion of the available cross-section $(D \times l)$ of the armature can be utilised.

3. The armature reactions, in consequence of the inner wires, are greater than with drum windings.

4. In order to obtain room for the inner wires or connections, the diameter of armature must be greater than is necessary to satisfy purely electrical requirements. This disadvantage is especially felt in the case of small machines.

5. The armature hub must be of gunmetal.

Advantages of the Drum.—1. Greater utilisation of armature cross-section for winding, as a result of which drum armatures for equivalent outputs are generally from 12 to 15 per cent. smaller than ring armatures.

2. Small armature reactions.

3. This method of winding can easily be adapted for multipolar machines with only two sets of brushes.

4. The body of the armature may be of cast iron.

5. The possibility of executing the winding by means of formers.

Disadvantages of the Drum.—1. Constructional difficulties: In repairing, the replacement of a single section necessitates the removal of nearly the whole winding. This objection is obviated by employing the method of winding designed and patented by the author, as used at the works of J. Farcot,

at Saint-Ouen, which allows any single section to be easily removed and replaced (*vide* Chapter IX.).

2. When neither toothed nor tunnelled cores are employed, driving pegs become necessary, as with large machines mere friction is not sufficient to effectually hold the conductors stationary.

3. Low insulation efficiency.

4. The number of commutator segments can only at the most be equal to half the number of inductors.

Other Methods.—The chief advantage of flat ring armatures (with side poles), apart from a slight saving of weight in the magnets because of the shortening of the magnetic circuit, is that they enable the magnets to be so designed that the armature may be removed without dismounting the magnets.

This feature is important in the case of large machines. Perhaps the only machine which utilises this advantage to its full extent is the Short dynamo—a type largely used in America, and described in Chapter IX. This advantage is in some degree counterbalanced by the facts: Firstly, the cost of the armature is greater. Secondly, after running for a time an axial eccentricity is developed, owing to the unequal magnetic pull to which the armature is subjected, and consequent uneven wearing of the bearings.

These objections are avoided in a discoidal ring machine of the author's design, as described in Chapter IX.

Of disc armatures, only two types seem to have met with much success — those of Desroziers and Fritsche. The difficulty in constructing this type is in obtaining sufficient rigidity of the armature—a difficulty which on the whole is excellently overcome in the Fritsche machine (*vide* Chapter IX.).

5. *Adjustment of Brushes—Causes of Sparking.*

The present remarks are of a preliminary nature only, inasmuch as a discussion of these phenomena and the calculations connected therewith assumes a more detailed knowledge of magnetic laws; hence fuller information will be given later (Chapter VI.).

Provision has to be made in all machines for a slight shifting of the brushes in order to secure sparkless running. Generators require a forward shift—that is, in the direction of

rotation; motors require a backward shift—that is, opposite to the direction of rotation.

Assuming the recognised view of the case—which we will not dispute here—this necessary shifting of the brushes is due to a twofold cause: Firstly, the armature reactions cause a distortion of the field and a corresponding displacement of the neutral axis. Secondly, a shifting is necessary to obtain the reversing E.M.F. to a coil after it is short-circuited.

Let us consider these two causes separately. So far as the armature reaction is concerned, it may be traced to causes resembling those producing the electromagnetic phenomena which arise when a current flows through a coil, only the effect is more complicated, since the magnetic axis of the armature is inclined at an angle relative to the axis of the magnets.

FIG. 34.

In Fig. 34, *m q* corresponds to the neutral axis. A current flows in the same sense through all the inductors above *m q*, whilst in those below *m q* the flow is in the opposite sense to that in the former. Hence, lines of induction are generated within the armature flowing as indicated in Fig. 35. While, however, the density of the lines of induction due to the field magnets is uniform along the pole cheek, *n o p*, the density due to armature currents increases respectively from a minimum at *o* to the leading or positive pole corner on the one side, and the trailing or negative pole corner on the other side, beyond which maximum points it rapidly decreases. (See Chapter VI.)

Plotting these induction values graphically (Fig. 35):

I. Induction due to field-magnet excitation;

II. Induction due to armature reactions;

we get the resultant Curve III. of the combined fields in a generator.

The current flow in a motor armature—having the same direction of rotation—is opposite in direction; hence, its

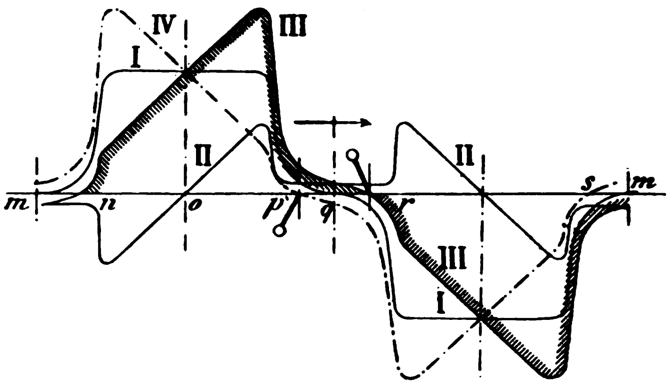

FIG. 35.

combined field takes the form of Curve IV. Since the brushes must be situated at the opposite extremities of a diameter where the induction is approximately zero, it follows that with a generator the shifting must be in the direction of

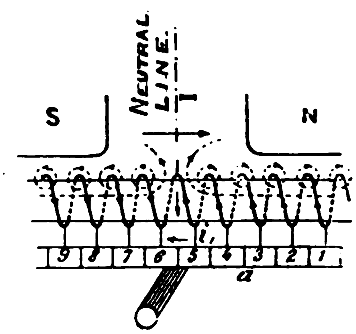

FIG. 36a.

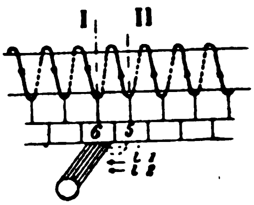

FIG. 36b.

rotation, and with a motor in the opposite direction. In order that the current may be properly commutated, the brushes must always be slightly in advance of the neutral axis (in the direction of rotation being understood). In a generator, this corresponds to an additional lead of the

brushes; in a motor, the lead is decreased, due to hysteresis effect. Hence, the possibility of providing well-designed and constructed motors with fixed brushes becomes apparent—a possibility of great importance when the motor is required both for forward and backward running.

An inspection of Fig. 36 shows that under certain circumstances the magnet field may be overpowered by the armature reaction field, thus reversing the polarity of the pole-pieces at their corners. Such conditions are, of course, only possible with badly-designed machines.

In order to avoid this—

$$\frac{N\ C}{2\ p_1\ D\ \pi} = k < \frac{20}{4\ \pi} \cdot B_l \cdot \frac{\delta}{b} \quad . \quad . \quad . \quad (26)$$

or,

$$N < 6{\cdot}37\ \frac{B_l}{C} \cdot \frac{\delta \cdot p \cdot p_1}{\beta} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (27)$$

where B_l = density of field per square centimetre;

p, b (as Fig. 35), $\beta = \dfrac{b \cdot 2p}{D\ \pi}$;

C = total current generated by the machine;

k = ampere-turns per centimetre length of the armature circumference, a quantity which will be found very convenient in calculations. (See Chapter VI.)

The causes of sparking may be explained by the aid of Fig. 37.

Looking at the winding in the direction of its motion, the current flow in any section has the direction of the hands of a watch up to the point of short-circuit, from which point the current is reversed.

Each inductor generates lines of force (armature reaction) which circle round it. The direction of the lines is shown by the dotted lines (Fig. 36*a*). When a section is short-circuited, the current it carries tends to decrease to nil; the magnetomotive force, and with it thereby the lines of force, also decrease.

We have seen that when the number of lines encircling a conductor varies, an E.M.F. is generated in the conductor. Determining the direction of this self-induced E.M.F. by

the rule already given, we find that it corresponds to that of the original current, which therefore cannot instantaneously die down, but disappears gradually according to a law to be discussed later.

Yet another phenomenon must be considered as giving rise to further complications. Immediately after the short-circuit has been broken the normal armature current flows round the coil, but in the reverse direction to that previously flowing round it. The causes which retarded the diminution of the original current serve now to check the growth of the reversed current, thereby forcing the latter to pursue its path to the brush through the air, as shown in segment 5. Sparking is the natural consequence, the intensity varying inversely with the ratio between the number of commutator segments and the total number of inductors.

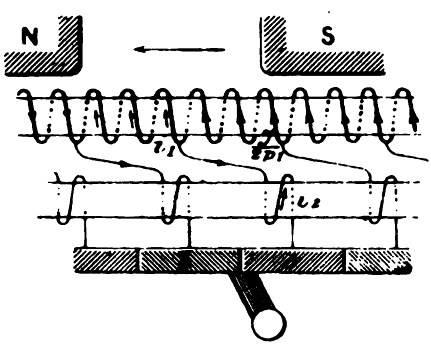

FIG. 37.

To prevent this sparking, the brushes must be set so far in advance of the neutral axis that a reversed current (c_3) may be generated in the coil during its period of short-circuit, not only of sufficient strength to neutralise the current already existing (c_1), but afterwards to approximate in value to the normal armature current.

Mention may here be made of Sayers's winding, which accomplishes the same end without shifting the brushes. (See Report of the Institution of Electrical Engineers, May, 1893.)

The armature is provided with two windings—the principal winding, which may be calculated in the ordinary way, and a compensation winding. Compared with ordinary windings, the distinctive feature is that the sections of the main winding are not connected directly to the commutator bars, but are arranged in series with the compensation coils, which latter are placed in certain positions to the rear of the main

winding. The direction of winding in the compensation coils is the reverse of the main winding.

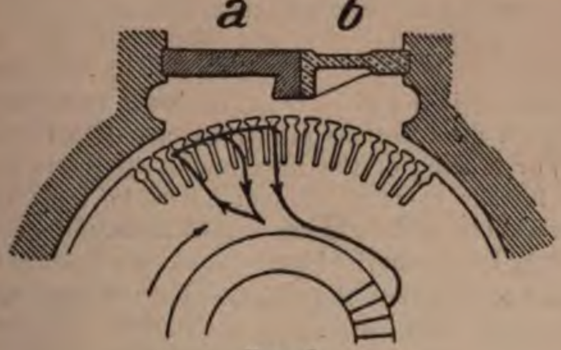

FIG. 38.

The arrangement is shown clearly in Fig. 37, in which both windings are shown upon separate armatures. This compensation winding provides the necessary commutating current, and as it is directly under the influence of the poles, a single turn will suffice to neutralise the self-induction of a large coil.

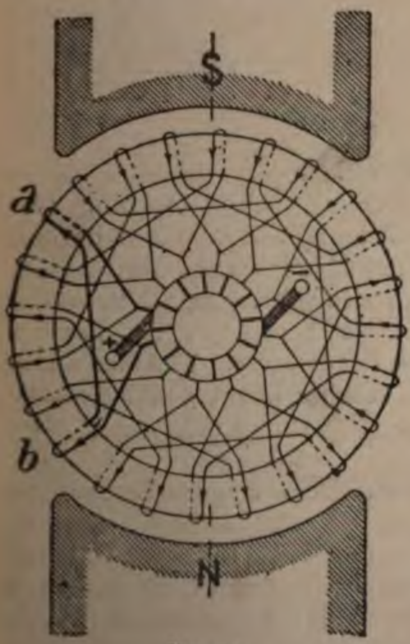

FIG. 39.

Fig. 38 shows another suggestion of Sayers's, in which an auxiliary pole is used. The principle involved is the same, but this latter plan is more readily constructed and regulated. The application of Sayers's method does not necessarily much increase the winding space, for it is only during short periods of time that a current circulates in the compensation windings; hence the section of wire

used may be comparatively small. A similar result is obtained by the arrangement shown in Fig. 39, due to Brown and Mordey. Here two coils, separated from each other, are grouped so as to connect adjacent commutator sections.

B. Losses in the Armature.

Equation (10) is not directly available for armature calculations, since it does not permit us to calculate the velocity, efficiency, or heating of the machine.

Before further calculations can be made, it is necessary that the various armature losses should be carefully estimated.

These may be summarised as:

1. Losses due to the resistance of the copper.
2. Hysteresis losses.
3. Foucault or eddy-current losses.
4. Friction losses.
5. Voltage losses through armature reactions.

In the strict usage of the term the latter is not an actual loss, since it corresponds to no equivalent waste of energy, yet it is given as causing a diminution of the effective output; in other words, there is a decreased voltage because of these reactions.

1. *Resistance Loss.*

Let C = total current in amperes.

p_1 = the number of circuits, each comprising two branches in parallel; it will be given by half the number of lines of brushes.

$e = \epsilon E$ = drop in pressure in volts.

R = resistance of the circuit between the brushes when at maximum temperature. The increase of temperature here reaches about 55°, hence the resistance coefficient $= \frac{1 \cdot 2}{60} = \frac{1}{50}$ (*vide* p. 18).

N = total number of conductors counted round the entire armature.

L = mean length of wire in a single turn of a Gramme winding, the length of a drum loop being the sum of the lengths of all the inductors with their connections, in metres, divided by N.

= sectional area of wire in square millimetres.

Then $$R = \frac{L . N}{50 . s . 2 p_1} = \frac{L . N}{100 . s . p_1} \quad . \quad . \quad . \quad (28)$$

$$e = \frac{C . R}{2 p_1} = \frac{L . N . C}{50 . s . 4 p_1^2} = \frac{L . N . C}{200 . s . p_1^2} \quad . \quad (29)$$

Hence the total armature loss in watts is

$$w = e\,C = \frac{L . N . C^2}{50 . s . 4 p_1^2} = \frac{L . N . C^2}{200 . s . p_1^2} \quad . \quad (30)$$

If we denote the current density—that is, the amperes per square millimetre sectional area—by c, then

$$C = s . c . 2 p_1,$$

whence $$e = \frac{L N . s c . 2 p_1}{50 s . 4 p_1^2} = \frac{L N c}{100 p_1} \quad . \quad . \quad . \quad (31)$$

$$w = \frac{N . s^2 . c^2 . 4 p_1^2}{50 . s . 4 p_1^2} = \frac{L N s c^2}{50} \quad . \quad . \quad . \quad (32)$$

$L N s$ is, however, nothing more nor less than the volume of the copper in cubic centimetres. Thus, it follows that for a total watt loss, w, the copper in the armature will be:

$$\text{Weight} = 0{\cdot}535 \frac{w}{c^2} \text{ kilogrammes (cold);}$$

or, allowing for a rise of t to about 55° C.:

$$\text{Weight} = 0{\cdot}45 \frac{w}{c^2} \text{ kilogrammes (approximately).} \quad . \quad (33)$$

This formula may be used for preliminary and approximate calculations.

Example 1.—What will be the weight of copper for a machine of 500 kw. capacity, allowing 1·5 per cent. loss and a current density $c = 2$ amperes per square millimetre?

$$\text{Weight} = 0{\cdot}45 \frac{0{\cdot}015 \times 500{,}000}{2^2} = 844 \text{ kilogrammes.}$$

VOLTAGE LOSSES PER 100 M. AT 0° C.:

c	e	c	e	c	e	c	e
0·1	0·166	0·9	1·50	1·7	2·83	3·0	5·00
0·2	0·333	1·0	1·66	1·8	3·00	3·2	5·33
0·3	0·500	1·1	1·83	1·9	3·16	3·4	5·66
0·4	0·666	1·2	2·00	2·0	3·33	3·6	6·00
0·5	0·833	1·3	2·16	2·2	3·66	3·8	6·33
0·6	1·000	1·4	2·33	2·4	4·00	4·0	6·66
0·7	1·166	1·5	2·50	2·6	4·33	4·5	7·50
0·8	1·33	1·6	2·66	2·8	4·66	5·0	8·00

Example 2.—Assume the armature of a bipolar machine, to give an output of 50 amperes at 65 volts, contains 200 inductors, each of 3·3 mm. diameter (bare), then

$$c = \frac{50}{2} \cdot \frac{1}{\frac{3{\cdot}3^2\,\pi}{4}} = 2{\cdot}9 \text{ amperes.}$$

Let the length of a single loop = 0·7 m., the total length of the wires between two brushes

$$= \frac{200}{2} \cdot 0{\cdot}7 = 70 \text{ metres.}$$

Whence, as will be seen from above table, the voltage loss is

$$e = 0{\cdot}7 \times 4{\cdot}83 = 3{\cdot}4 \text{ volts;}$$

or, taking rise of temperature into account = 4·1 volts, so that the total loss in watts is

$$4{\cdot}1 \times 50 = 205 = 6{\cdot}3 \text{ per cent.}$$

Example 3.—What will be the armature losses in a six-pole machine designed for an output of 1,000 amperes at 20 volts, if $N = 80$, $p_1 = 3$, $d = 9$ millimetres? ($s = 63{\cdot}5$ square millimetres.)

Length of a single loop = 0·9 m.;

Total length of winding between two brushes $= \frac{80 \times 0{\cdot}9}{6}$

$= 12$ m.;

Current density $c = \frac{1{,}000}{2\,p_1 \cdot s} = \frac{1{,}000}{2 \times 3 \times 63{\cdot}5} = 2{\cdot}6$ amperes.

Loss of pressure (calculated from table):

$$= 4{\cdot}33 \times 0{\cdot}12 = 0{\cdot}52 \text{ volts } (0{\cdot}62 \text{ volts, hot});$$

and total loss in watts:

$= 0{\cdot}52 \times 1{,}000 \times 520$ watts $= 2{\cdot}6$ per cent. (3·1 per cent. hot).

A table to assist such calculations is given at the end of this book.

2. *Hysteresis.*

If we imagine the iron core of an armature to be cut through in the direction of any diameter, and then observe

its state of magnetisation during a complete revolution, we shall see that the lines of induction undergo as many changes in direction as the machine has poles. The minimum degree of magnetisation always occurs when the diameter coincides with the axis through a pair of poles, in which position it = 0. From this point the density of the lines increases almost proportionally with the motion till it attains a maximum value at the neutral axis, whence it again diminishes to zero. The iron, however, possesses a certain inertia which tends to maintain the magnetisation at its maximum strength. As a natural consequence, the density of lines of induction

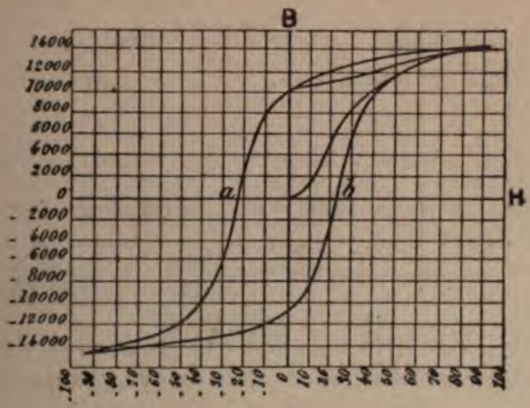

FIG. 40.

corresponding to a given instantaneous strength of the magnetising current will be smaller if that current is rapidly increasing than it would be for a constant current of the same value.

Fig. 40 (from Prof. S. P. Thompson's work) shows such a cycle—the outcome of experiments with soft iron. The area enclosed between the curves *a* and *b* represents the so-called hysteresis loss. Within the limits occurring in actual practice, this loss is exactly proportional to the number of periods or cycles, ω, through which the iron has been taken, and to the volume of iron experimented on.

Our thanks are chiefly due to Prof. J. A. Ewing for experimental investigations into this phenomena; also for

the figures in column *a* of the appended table (see *Phil. Trans.*, Part IV., No. 238, 1885; further, *Electrician*, June, 1890, etc.) Column *b* relates to recent experiments with five different transformer plates manufactured by Messrs. Sankey and Sons, London (see *Elektrotechnische Zeitschrift*, May, 1895).

Lines of Induction per Square Centimetre. B.	Loss in Watts per Cubic Centimetre during a Complete Cycle. Column *a*.	Column *b*.
1,000	—	90 to 120 × 10^{-7}
2,000	480 × 10^{-7}	220 to 400
3,000	800	410 to 790
4,000	1,230	645 to 1,220
5,000	1,700	910 to 1,710
6,000	2,200	1,200 to 2,250
7,000	2,760	1,530 to 2,940
8,000	3,450	1,920 to 3,720
9,000	4,200	2,320 to 4,550
10,000	5,000	—
11,000	5,820	—
12,000	6,720	—
13,000	7,650	—
14,000	8,650	—
15,000	9,670	—

It may be as well to mention that the various plates used in the above recorded tests were of very superior quality, which, indeed, was necessitated by their employment for transformer purposes, in order to ensure the least possible hysteresis loss.

The laws of hysteresis with relation to the chemical constituents of iron are, as yet, but little known. It would, indeed, appear that the method of treatment during manufacture plays a more important *rôle* than the chemical composition itself.

An interesting observation has been communicated by Messrs. Oeking and Co. to the *Elektrotechnische Zeitschrift* (May 25, 1897). According to this, the hysteresis loss in a sample of iron was increased 10 per cent. by annealing. A similar observation has also been made by the author, in that the hysteresis loss in completed machines is generally somewhat greater than would be anticipated from tests made on the iron discs previously to their being built up.

Likewise, after long periods of working, transformers show increased losses due to hysteresis.

The published works by Mr. Chas. Proteus Steinmetz (see *Elektrotechnishe Zeitschrift*, vol. iv., 1892), wherein very simple formulæ for the calculation of hysteresis losses are given, will be found of great practical value.

Taking $\omega = \frac{n\,p}{60}$ as the periodicity;

V the volume of the iron core in cubic centimetres; and

η a numerical coefficient,

then, according to Steinmetz—

$$\text{Hysteresis loss} = \eta\,B^{1\cdot 6} \,.\, \omega \,.\, V \,.\, 10^{-7} \text{ watts} \quad . \quad (34)$$

The values of η and $\eta \,.\, B^{1\cdot 6}$ may be taken from Tables IV., V., and VI., given at the end of the book.

According to Table VI., we find that the figures appearing in column *a* of the table on p. 48 correspond to a coefficient η = about 0·002. Generally speaking, the hysteresis losses in the iron employed in the construction of continuous-current machines are somewhat larger, η = about 0·003.* This is due to the iron being used in large continuous masses.

Example 1.—The six-pole machine mentioned on p. 46 runs at 800 revolutions per minute. What will be the loss through hysteresis if the cubic contents of its armature core = 19,000 cubic centimetres, and the maximum saturation amounts to 8,000 lines?

$$\text{Periodicity } \omega = \frac{p \,.\, n}{60} = \frac{3 \times 800}{60} = 40.$$

Assuming that η = 0·003, then, basing our calculation on Table VI., the loss in watts = $5{,}274 \times 40 \times 19{,}000 \times 10^{-7}$ = 400 = 2 per cent.

We have still to answer the question, What change should we have to effect in the dimensions of the iron core if, instead of the above 400, a loss of only 300 watts was to be permitted?

* In connection with some samples manufactured at Audincourt, η = 0·0015.

Estimating 21,000 cubic centimetres instead of 19,000, and allowing a loss of 300 watts—

$$\eta \cdot B^{1.6} = \frac{300 \cdot 10^{-7}}{40 \cdot 21{,}000} = 3{,}580 \text{ (approximately)}.$$

Referring to Table VI., we find that for this calculation the value of B amounts to between 6,000 and 6,500 lines; the desired saturation is therefore about 6,300 lines.

Example 2.—Two qualities of iron are given, of which the first possesses a coefficient $\eta = 0{\cdot}004$, and the second $\eta_1 = 0{\cdot}003$. The cost price of the former is ·35 fr. per kilogramme, that of the latter quality being ·45 fr. per kilogramme. Allowing the loss in watts to be equal, which of these two qualities will prove the more economical in the construction of an armature?

The external diameters of the armatures are the same in both cases: S = cross-section in square centimetres; L = mean circumference.

$$B = \frac{\phi}{S}; \ V = S \times L.$$

For equal losses we must have

$$0{\cdot}004 \left(\frac{\phi}{S}\right)^{1.6} . S . L = 0{\cdot}003 \left(\frac{\phi}{S_1}\right)^{1.6} . S_1 L_1.$$

Assuming the approximate value of $L_1 = 1{\cdot}07$ L, then

$$\frac{S_1}{S} = \left(\frac{0{\cdot}003}{0{\cdot}004} \times 1{\cdot}07\right)^{\frac{1}{0\cdot6}} = 0{\cdot}669.$$

$$\frac{\text{Cost price of the better iron}}{\text{Price of the inferior iron}} = 0{\cdot}669 \times 1{\cdot}07 . \frac{45}{35} = \mathbf{0{\cdot}92.}$$

We thus see that in this instance the difference in initial cost is not very considerable. Supposing, however, that $\eta = 0{\cdot}003$ and $\eta_1 = 0{\cdot}002$, the other ratios will be:

$$\frac{S_1}{S} = \left(\frac{0{\cdot}002}{0{\cdot}003} . 1{\cdot}07\right)^{\frac{1}{0\cdot6}} = 0{\cdot}58.$$

$$\frac{\text{Cost price of the better iron}}{\text{Price of the inferior iron}} = 0{\cdot}58 \times 1{\cdot}07 \times \frac{45}{35} = \mathbf{0{\cdot}81.}$$

These two calculations demonstrate that, under all circum-

stances, it is better in the long run to use a superior quality of iron, even if its initial cost is somewhat higher.

3. *Loss through Foucault Currents.*

Foucault or eddy currents occur not only in the copper of the armature, but also in the iron itself, supposing this latter to be insufficiently laminated. It may be given as a fundamental rule that whenever massive metallic bodies are moved in a magnetic field so as to cut lines of induction, or are subjected to variable magnetisation, they become the seats of Foucault currents. The origin of these currents is attributable to the unequal distribution of the lines of induction through the masses; local currents are consequently produced which exert a counter-magnetising influence, thereby reacting on the useful lines of induction so as to obstruct the passage of the latter. A peculiar characteristic to be remarked in connection with Foucault currents is that they confine themselves more or less to the outer surface—that is to say, their density decreases from the surface inwards, and thus penetration is diminished as the thickness of the mass is increased. Owing to this peculiarity these currents are very liable—providing the air gap is small—to produce eddies in the pole corners of the field magnets (Fig. 41). This also occurs when smooth-surface cores are overwound with massive copper inductors. It is, therefore, inexpedient to wind smooth-surface cores with inductors of such large sectional area as may be employed with toothed cores.

FIG. 41.

In the last-mentioned type the iron teeth provide paths whereby the lines of force complete their circuits with greater facility, relatively fewer lines penetrating, for this reason, into the copper. A diameter of from 15 mm. to 20 mm. is generally reckoned as the maximum practicable for conductors.

Another characteristic of Foucault currents is that they

increase in proportion to the square of the periodicity. When this latter is very high the magnetic effect will be correspondingly great, and this circumstance is not without certain advantages which are utilised in practice.

For instance, cast iron may be unhesitatingly employed for the cover plates arranged parallel with the laminations of transformer cores, as the screening effect with a periodicity of from 40 to 50 almost entirely checks any penetration of lines. The armature hubs or spiders of Gramme-ring machines, on the contrary, must always be of gunmetal, since they would become too heated if made of cast iron. Respecting this latter phenomena, the author has been able to make some observations with a three-phase alternating-current dynamo possessing a Gramme-wound armature mounted upon a cast-iron hub. Not only did this hub heat to a greater extent than is customary, but also when the machine was working on a load considerable difference of pressure between its three phases was observed.

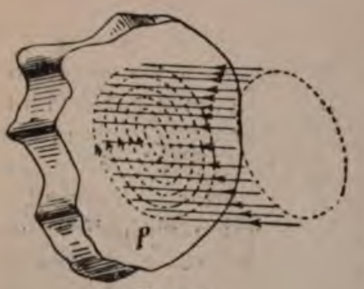

FIG. 42.

Unfortunately, the fundamental laws governing the origin of eddy currents have not, up to the present time, been sufficiently investigated to permit of an exact estimate of their magnitudes. We may, however, obtain an approximate conception of their nature and disposition by the aid of Fig. 42. Let us suppose that the massive plate, P, be subjected to a variable induction. We may further imagine the plate to be composed of a number of concentrically-arranged rings, in which, as has been previously shown, currents having certain definite directions will be produced. Their magnitudes will depend, on the one hand, upon the number of lines cut—the latter being directly proportional to the square of the diameter; and on the other hand, this magnitude will be inversely proportional to the resistance of a ring—that is, to its diameter.

The eddy currents consequently decrease in strength in passing from the outer rings towards the centre.

The production of Foucault currents in the iron core of an armature may be traced to similar causes. In order to obtain a clearer conception, let us picture to ourselves an armature built up from insulated wires, arranged parallel with the axis of rotation. An E.M.F. will consequently be induced in each of these wires during the rotation of the armature in a magnetic field, the value for any individual wire depending upon its distance from the axis and on the number of lines of induction circling round it. The greatest difference of potential will exist at *a* (see Fig. 43); whilst at *b* the pressure = 0, as no relative change in the number of lines there takes place.

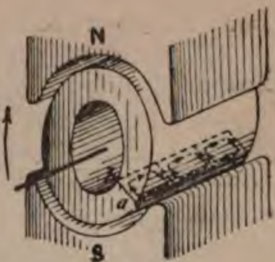

FIG. 43.

This phenomenon will also occur when the armature is formed from solid iron, resulting, as in the previous example, in a circulation of induced currents through the iron parallel to the axis of rotation. In practice, these currents are checked by constructing the armature core of sheet-iron discs (generally 0·5 mm. to 0·6 mm. in thickness), the surfaces of which are either oxidised or electrically insulated by the interposition of thin sheets of paper.

A method, formerly much in vogue, in which the cores of armatures were composed of iron wire wound upon formers, has recently become almost obsolete. One is inclined to seek the reason for this in the fact that the magnetic resistance of such armatures is greater than when iron discs are employed. It is, nevertheless, to be observed that the total magnetic resistance of a machine is only very slightly affected when this method is adopted.

The following formulæ, suggested by Prof. J. A. Fleming, enable us to estimate the Foucault currents for both types of construction:

With iron-wire cores:

$$\text{Loss in watts} = \frac{(d \cdot \omega \cdot B_{max.})^2 \, V}{4 \cdot 10^{12}} \quad . \quad . \quad . \quad (35)$$

whereas when discs are used:

$$\text{Loss in watts} = \frac{16\,(a \,.\, \omega \,.\, B_{max.})^2\, V}{10^{12}} \quad . \quad . \quad (36)$$

where d = diameter of the wire in centimetres;
ω = periodicity per second;
a = thickness of the discs in centimetres;
V = total volume of iron in cubic centimetres.

Equation (36) is only applicable when $a \leqq 0{\cdot}1$.

Example 1.—What will be the loss in watts, through Foucault currents, in a bipolar machine of 10 kw. capacity, working at 1,000 revolutions per minute, supposing V = 9,000; $B_{max.}$ = 12,000; a = 0·05; ω = 16·7?

$$\text{Loss in watts} = \frac{16\,(0{\cdot}05 \times 16{\cdot}7 \times 12{,}000)^2\, 9{,}000}{10^{12}} = 14{\cdot}4$$
$$= 0{\cdot}14 \text{ per cent.}$$

Example 2.—Given the following data, it is required to estimate the loss in watts owing to eddy currents in a six-pole machine:

Output = 26·7 kw.;
Speed = 720;
$B_{max.}$ = 10,000;
a = 0·05;
V = 23,000;
ω = 36.

$$\text{Loss in watts} = \frac{16\,(0{\cdot}05 \times 36 \times 10{,}000)^2\, 23{,}000}{10^{12}} = 120$$
$$= 0{\cdot}43 \text{ per cent.}$$

The two preceding examples show that the calculation of eddy currents in the iron cores of armatures is only necessary in connection with machines having a high periodicity, and may be entirely neglected when bipolar machines are under consideration.

It must not be concluded from this, however, that Foucault currents may be totally ignored. Their production occurs principally in the end-plates which serve to clamp the core laminations together; further, the teeth of grooved armatures are seats of trouble when the slots or grooves are not carefully milled and any ragged edges afterwards trimmed off. Nor must mention of the winding itself be forgotten.

For the rest it may be taken that even in well-designed and carefully-built machines the loss due to Foucault currents does not amount to less than from 40 to 50 per cent. of the total hysteresis loss. Experience, on the other hand, has shown that with machines of faulty construction the loss may be three to four times as great.

An exact estimation of these losses cannot be made. It is, nevertheless, as well, when estimating the effective output of a machine, to consider the nearest approximate value ascertainable.

4. *Friction Loss in the Bearings.*

The several stresses to which the bearings of a dynamo are subjected depend upon the weight of the armature, W, and the pull, Z, of the driving belt. Since the latter acts, as a rule, in a horizontal direction, the resultant pressure on the bearings is given by

$$P = \sqrt{G^2 + Z^2}.$$

But as it is in many cases advantageous to be able to determine the approximate friction losses without previously entering into calculations as to the weight of the armature, we will endeavour to establish a more general formula.

Fortunately, the comparative weights of different types of dynamo machines, for a given specific output W_s (kilowatts at 1,000 revolutions), (see p. 63), do not vary to such an extent as to preclude the possibility of their being dealt with, up to a certain point, through the medium of one common formula.

The average total weight of a machine: *

$$G = 175 \cdot W_s^{\frac{2}{3}} \text{ kilogrammes} \quad . \quad . \quad . \quad . \quad (37)$$

or,

$$G = 386 \; W_s^{\frac{2}{3}} \text{ lbs.}$$

In small machines, the maximum deviation from the number

* For motors, $\frac{746 \times \text{H.P.}}{n}$ must be taken as the value of W_s. It may be added that the coefficient for any distinctive type remains constant for that type, irrespective of the output of the machine under consideration. In calculating the friction losses, a slight error in the adopted coefficient has little influence, since he pull of the driving belt is generally greater than the weight.

so obtained reaches at the highest 30 to 35 per cent.; with large machines the deviations are generally less.

Of this weight, about 20 per cent. is due to the armature, in smaller machines the proportion being still less. By assuming the armature to have 20 per cent. of the total weight of the complete machine for all sizes, we thereby make some allowance in the calculation for the magnetic pull, which is larger in small machines.

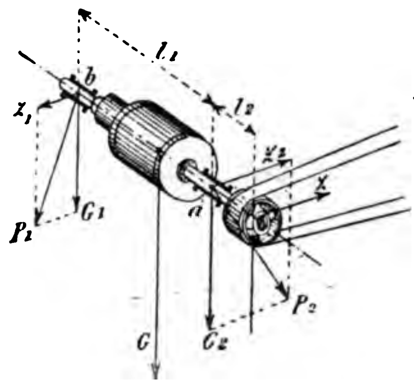

FIG. 44.

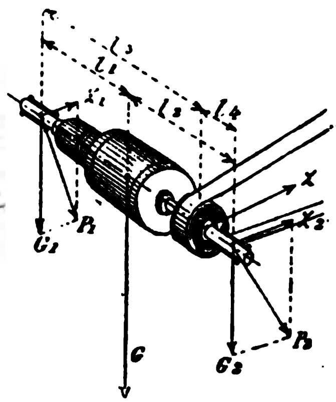

FIG. 45.

Let W_s = specific output (in kilowatts at 1,000 revolutions per minute);
W = output in kilowatts at n revolutions;
v = velocity of the driving belt; then

Weight of armature

$$G = 35\ W_s^{\frac{2}{3}} = 3{,}500 \left(\frac{W}{n}\right)^{\frac{2}{3}} \text{ kilogrammes} \quad . \quad (38)$$

or,

$$G = 7{,}700 \left(\frac{W}{n}\right)^{\frac{2}{3}} \text{ lbs.}$$

Maximum pull, Z, of the driving belt =

$$Z = \frac{3}{0{\cdot}89} \cdot \frac{W \times 1{,}000}{9{\cdot}81 \times v} = 345 \frac{W}{v} \text{ kilogrammes} \quad . \quad (39)$$

when v is measured in metres per second; and

$$Z = 2{,}500 \frac{W}{v} \text{ lbs.,}$$

when v is measured in feet per second; with a mean efficiency of 89 per cent.

We may distinguish between two cases:

(*a*) Belt pulley situated outside the bearings (Fig. 44).

(*b*) Belt pulley and armature placed between two bearings (Fig. 45).

Another modification occurs when there are three bearings, but it is better in this case to set down the friction loss approximately at 3 to 3·5 per cent., leaving the more exact estimations until afterwards.

Under ordinary conditions the pressures will be distributed approximately as follows:

(*a*) Pulley outside bearing—*Pressure on bearing a*:

$$P_1 = \sqrt{4{,}700{,}000\left(\frac{W}{n}\right)^{\frac{4}{3}} + 180{,}000\left(\frac{W}{v}\right)^2} \quad . \quad (40a)$$

in kilogrammes, when v is measured in metres per second; also

$$P_1 = \sqrt{2{,}280{,}000\left(\frac{W}{n}\right)^{4} + 94{,}000{,}000\left(\frac{W}{v}\right)^2}$$

in pounds, when v is measured in feet per second.

Pressure on bearing b:

$$P_2 = \sqrt{1{,}800{,}000\left(\frac{W}{n}\right)^{\frac{4}{3}} + 6{,}900\left(\frac{W}{v}\right)^2} \quad . \quad (40b)$$

in kilogrammes, when v is measured in metres per second; also

$$P_2 = \sqrt{8{,}800{,}000\left(\frac{W}{n}\right)^{\frac{4}{3}} + 3{,}620{,}000\left(\frac{W}{v}\right)^2}$$

in pounds, when v is measured in feet per second.

For small machines, with outputs below 10 kw., this formula gives a bearing pressure about 10 per cent. too great.

(*b*) Pulley between bearings—*Pressure on bearing a*:

$$P_1 = \sqrt{\left(G\frac{l_2}{l_1 + l_2}\right)^2 + \left(\frac{l_3}{l_3 + l_4}\quad\right)^2}$$

$$= \sqrt{2{,}300{,}000\left(\frac{W}{n}\right) + 8{,}200\left(\frac{W}{v}\right)^2} \quad . \quad (41a)$$

in kilogrammes, when v is measured in metres per second; also

$$P_1 = \sqrt{11{,}100{,}000 \left(\frac{W}{n}\right)^{\frac{4}{3}} + 4{,}160{,}000 \left(\frac{W}{v}\right)^2}$$

in pounds, when v is measured in feet per second.

Pressure on bearing b:

$$P_2 = \sqrt{\left(G \frac{l_1}{l_1 + l_2}\right)^2 + \left(\frac{l_4}{l_3 + l_4} Z\right)^2}$$

$$= \sqrt{4{,}000{,}000 \left(\frac{W}{n}\right)^{\frac{4}{3}} + 3{,}300 \left(\frac{W}{v}\right)^2} \quad . (41b)$$

in kilogrammes, when v is measured in metres per second; also

$$P_2 = \sqrt{19{,}000{,}000 \left(\frac{W}{n}\right)^{\frac{4}{3}} + 1{,}720{,}000 \left(\frac{W}{v}\right)^2}$$

in pounds, when v is measured in feet per second.

(Compare the weights of armatures given in Chapter X.)

Knowing the pressure, P, to which the bearings are subjected, the peripheral velocity, v_1, of the shaft within the bearings, and the friction coefficient $f = 0{\cdot}05$ to $0{\cdot}1$, we may calculate the friction loss:

$$\text{Friction loss} = Pv_1 f \text{ kilogrammes} = 9{\cdot}81 \times Pv_1 f \text{ watts} \quad . (42)$$

Example.—What friction loss may be anticipated in a machine of 40 kw. output, making 700 revolutions per minute, with the driving pulley placed outside one of its bearings?

Velocity of the belt ... ... $v = 16{\cdot}5$ m.
Peripheral speed of the shaft within $a = 2{\cdot}75$ m.
" " " $b = 2{\cdot}00$ m.
Friction coefficient... ... ... $= 0{\cdot}067$ m.

Pressure on bearing at a =

$$\sqrt{4{,}700{,}000 \left(\frac{40}{700}\right)^{\frac{4}{3}} + 180{,}000 \left(\frac{40}{16{\cdot}5}\right)^2} = 1{,}670 \text{ kilogrammes};$$

Pressure on bearing at b =

$$\sqrt{1{,}800{,}000 \left(\frac{40}{700}\right)^{\frac{4}{3}} + 6{,}900 \left(\frac{40}{16{\cdot}5}\right)^2} = 282 \text{ kilogrammes.}$$

Loss in watts = $9{\cdot}81 \times 0{\cdot}067\ (1{,}070 \times 2{\cdot}75 + 282 \times 20)$
= 2,280 watts = 5 per cent. of the total energy.

5. *Efficiency—Heating.*

Let W = the useful watts; in motors W = 746 × the H.P. generated;

Σw = the sum of all the losses—*i.e.*, the sum total of the following values:

w_a = watts lost in the copper of the armature;

w_h = watts lost due to hysteresis:

w_f = watts lost due to Foucault currents;

w_r = friction loss expressed in watts;

w_m = watts lost in the field magnets = (magnetising current)^2 × resistance of the magnet windings;

ζ = the efficiency; then

$$\zeta = \frac{W}{W + \Sigma w},$$

or,

$$\zeta = \frac{W}{W + w_a + w_h + w_f + w_r + w_m} \quad . \quad . \quad . \quad (43)$$

We again venture to remind the reader of the foregoing remarks upon Foucault currents (p. 55). Should very exact estimates of the efficiency be desired, we must not neglect to take into account the friction of the brushes—at all events, when the machine in question is fitted with carbon brushes.

The friction coefficients given below—referring to a circumferential commutator speed of 5 m. per second—were obtained from experiments conducted by Messrs. E. V. Cox and H. W. Buck (see *Elektrotechnische Zeitschrift*, Nov. 5, 1896):

Carbon brushes, radially set, 1· dry; 0·3 lubricated.
Carbon brushes, tangentially set, 0·64 dry; 0·2 lubricated.
Copper brushes, tangentially set, 1·31 (!) dry; 0·32 lubricated.

For greater velocities these coefficients must be multiplied by $\left(1 - \frac{v - 5}{40}\right)$.

The following example shows that the loss due to friction at the brushes is not always negligible:

A dynamo has an output of 180 amperes at 100 volts, and is provided with radially-set carbon brushes, the circumferential speed of the commutator being 9 m. per second. The area of the contact surface should not be less than 0·15 square

centimetre per ampere, with a pressure equivalent to about 0·15 kgrm. per square centimetre. The total pressure of the two lines of brushes will therefore be

$$2 \times 180 \times 0{\cdot}15 \times 0{\cdot}15 = 8{\cdot}1 \text{ kilogrammes.}$$

Friction coefficient (lubrication assumed)—

$$0{\cdot}3\left(1 - \frac{9-5}{40}\right) = 0{\cdot}27.$$

Consequently the friction loss, expressed in watts, is

$$w_r = 9 \times 8{\cdot}1 \times 0{\cdot}27 \times 9{\cdot}81 = 193 \text{ watts} = 1{\cdot}07 \text{ per cent.}$$

Should the lubrication be insufficient, this loss may easily reach a value twice as great.

Each of the above-mentioned losses is accompanied by an evolution of heat—that is to say, by a corresponding increase in the temperature of that part of the machine in which the loss occurs. The efficiency of a continuous-current dynamo, apart altogether from mechanical questions, depends upon its capacity for radiating heat, or, in other words, upon the extent of its cooling surface.

The maximum efficiency of a machine may, without difficulty, be determined from equation (43). We must first substitute $C \,.\, E$ and $C^2 R$ for W and w_a respectively (where R = total resistance of the armature). Further, writing $w_h + w_f + w_r + w_m = w_x$ = a constant, and differentiating the equation so obtained with respect to C, equating the differential coefficient to zero, we obtain :

$$\zeta = \text{maximum for } w_a = w_x;$$

the current corresponding to the maximum efficiency being

$$C = \sqrt{\frac{w_x}{R}}.$$

General formulæ giving the increases of temperature to which machines are liable cannot, unfortunately, be established. We must therefore content ourselves with the formulæ long since proposed by Mr. W. B. Esson (see *Journal* of the Institution of Electrical Engineers, vol. xix.), which, when applied with due circumspection, lead to results very approximately true.

(*a*) For armatures: Increase of temperature in C.° =

$$\frac{225 \times \text{watts lost in the armature}}{\text{cooling surface in square centimetres}} \quad . \quad . \quad (44)$$

(*b*) For magnets: Increase of temperature in C.° =

$$\frac{335 \times \text{watts lost per coil}}{\text{superficial area of a coil in square centimetres}}. \quad (45)$$

(If Fahrenheit degrees and square inches are used, the coefficients become respectively 67 and 100.)

It may be as well to observe that, when considering ordinary armatures, only the cylindrical surfaces and the ends must be taken into account; in the case of small armatures, indeed, only one of the latter. If air has access to the interior of the armature, its diameter not being too small, then about one-third of the interior surface area may be added to obtain the effective cooling surface.

In the case of the field magnets, the inner surfaces of the curving pole-cheeks are not counted; the lateral surfaces alone being included in the estimate.

Example.—If the diameter of an armature wound for a 10-kw. machine = 24 cm., length = 40 cm. approximately (measured over the winding), and, further, the diameter of that end-face adjacent to the driving pulley = about 16 cm., it follows that its cooling surface = $24\pi \times 40 + \frac{16^2\pi}{4} = 3{,}200$ square centimetres. Loss in the copper = 260 watts; loss through hysteresis = 300 watts—total, 560 watts; then its increase of temperature according to Esson = $\frac{225 \times 560}{3{,}200} = 40°$ C. above that of the surrounding air. Assuming the engine-room temperature to be at 20° C., it consequently follows that the temperature of the armature when working will be equal to about 60° C. Formula (44) is not quite correct, inasmuch as it makes insufficient allowance for the speed of the armature.

According to Messrs. A. H. and C. E. Zimmermann ("Dynamo-Electric Machinery," fifth edition, Prof. S. P. Thompson) the value of the heat, expressed in watts, which a square inch of cooling surface radiates is given:

For a speed of	0 ft. per	min.,	by	0·01	watt per degree C.
,, ,, ,,	1,000 ,,	,,	,,	0·018	,, ,,
,, ,, ,,	3,000 ,,	,,	,,	0·022	,, ,,

Or, if the surface area be measured in square centimetres, this law may be expressed by the formula:

Increase of temperature in the armature =

$$\frac{645 \times \text{watts lost}}{\text{surface } (1 \times 0{\cdot}3\ \sqrt{v})} \text{ C.}^\circ \quad . \quad . \quad . \quad . \quad . \qquad (46)$$

where v = circumferential velocity in metres per second.

Generally speaking, a temperature increase of from 40° to 45° C. above that of the engine-room—the latter being taken at 25° C. is regarded as normal. Some manufacturers overstep this limit, but the practice is not wise, as, when subjected to excessive heating, the insulation is deteriorated, after a few years being completely destroyed.

To be quite safe, the radiating surfaces should be proportioned approximately as follows: 8 to 9 square centimetres (1·2 to 1·4 square inch) of cooling surface per watt for the magnets, and 5·5 to 6·5 square centimetres (0·85 to 1 square inch) of cooling surface per watt for the armature.

An exception to this rule is found in machines which are destined for tropical climates or for shiplighting, in either of which cases the temperature of the dynamo-room may attain to 40° C. In this connection the English Admiralty is especially stringent, permitting a maximum increase in the temperature of only 17° C., which is, perhaps, erring on the side of extreme caution.

C. Alteration of an Armature to obtain a Different Pressure.

(Equation 10) $$E = \frac{n \cdot \phi \cdot N}{60 \cdot 10^8} \frac{p}{p_1}$$

shows that the output of a machine may be augmented at will by increasing its speed. The maximum output of a machine is therefore dependent upon its heat-radiating capacity, and the ultimate increase of temperature, which may be ascertained from equations (44) to (46). We start from the supposition that the conditions of magnetisation are such as to ensure sparkless running, even when the machine is overloaded. A further condition is that the circumferential velocity must not exceed a certain value (20 m. to 25 m. per second, corresponding to 70 ft. to 80 ft.).

On the other hand, American manufacturers, notably the Westinghouse Company, admit much higher velocities.

If we take a machine and increase its speed beyond that which corresponds to the maximum output, determined by the extent of its cooling surface, its output will no longer increase proportionately to the speed, but will remain practically constant. Should, on the other hand, the speed be diminished, a slight gain becomes apparent. Nevertheless, within certain limits, the output of a machine may be regarded as proportional to the speed of its armature.

This rule is subject to limitation only in so far as the air-gap between the armature and pole-pieces varies with different windings. If the air-gap is increased for a new winding, ϕ remaining constant, it may happen that the space to be disposed of for winding the field magnets is found to be insufficient to give the requisite number of ampere-turns.

Manufacturers generally classify machines by stamping each individual type with some distinctive letter or letters, adding the output in watts, or the horse-power, or the current in amperes. D C 50 might, for instance, denote a continuous-current dynamo of 50 kw. capacity, and D A 25 an alternating-current dynamo of 25 h.p. This practice is disadvantageous, in that it gives no indication, and allows, moreover, of no direct estimation, regarding the output of a machine at different speeds. As an alternative it would appear much more logical to signify the specific output—that is to say, the output (in kilowatts) at a uniform speed of 1,000 revolutions per minute; by this means the selection of a particular type, running at an abnormal speed, would be greatly facilitated. An example may be given to illustrate this. Suppose that the following table has been made out for an ordinary type of dynamo:

Number.	1	2	3	4	5
Kilowatts	5	10	16	24·5	33
Revolutions	1,250	1,000	800	700	600
Specific output in kilowatts at 1,000 revolutions per minute	4	10	20	35	55

Suppose, now, that for some particular purpose a machine yielding, say, 20 kw. at 400 revolutions per minute, is required;

this is equivalent to a specific output of $\frac{20 \cdot 1,000}{400} = 50$. Of the types included in the above table, we at once perceive that the one yielding a specific output of 55 kw. most nearly approximates to these conditions; and, indeed, will presumably suffice for our requirements, providing its normal pressure be 200 to 300 instead of 100 volts.

Let us denote by E, C, and n the electrical values relative to machine No. 5, and by E_1, C_1, and n_1 those appertaining to a machine remodelled to meet our requirements.

With ϕ remaining a constant value, it follows from equation (10) that

$$N_1 = N \cdot \frac{E_1}{E} \cdot \frac{n}{n_1}.$$

Employing equation (29) we may now determine the necessary cross-section of wire:

$$s_1 = \frac{L \cdot N \cdot C}{50 \cdot e \cdot 4 p_1^2};$$

whence $$d = \frac{1}{12{\cdot}5\, p_1} \sqrt{\frac{L \cdot N \cdot C}{e}}.$$

When only an approximate estimate is required, the above equation is commonly written:

$$s = \frac{C}{c\, 2\, p_1} \quad \ldots \ldots \quad (47)$$

in which c, the current density per square millimetre section of the wire, varies between 5 and 1·5; the value of c for currents up to 1,500 amperes is given with sufficient accuracy by the equation—

$$c = 90\, \epsilon,$$

where $\epsilon = \frac{e}{E}$ varies between 0·06 and 0·02.

Assuming that the points of collection in the original and converted machines are to remain equal in number, then for the same percentage drop in the voltage

$$\frac{S_1}{S_2} = \frac{C_1}{C_2} \quad \ldots \ldots \quad (48)$$

In practice, however, a slight modification in both the value of the voltage loss, $\epsilon\, E = e$, and the total induction

will generally prove necessary, so that conclusions drawn from the above formula must only be regarded as approximately accurate.

Wires and their Insulation.

Besides wires of circular section, insulated wires of rectangular section are also in use. These do not, however, commend themselves in practice, their use being attended with the disadvantages that, in the first place, they are very difficult to wind; and secondly, their insulation—which, it may be observed, occupies somewhat more space than the insulation of wires of circular section, assuming the same number of layers—is easily injured. Large armatures are either wound with solid copper bars or with cables of any suitable cross-section. When bars of any rectangular section are employed, it is always advisable to round off their edges. The manufacture of cables is greatly facilitated, and the cost somewhat lessened, when a form similar to that shown in Fig. 46 is used. In the type Fig. 46, *b* is composed of two conductors of circular section, the interstices being filled up with thin wires. The use of cables in preference to solid bars or wires is not only a question of the greater facility with which their winding may be executed, but is also advantageous in lessening the detrimental effects due to the production of Foucault currents; they are therefore largely used with smooth armatures when a great current-carrying capacity is required.

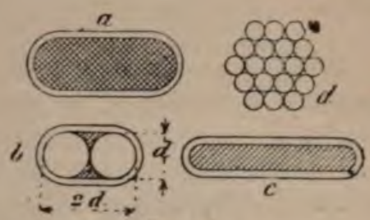

FIG. 46.

For equal diameters, cables have an effective sectional area of some 22 to 25 per cent. less than solid wires. Further, their component strands generally number 19 or 37 (compare Table III. at end of book).

The ultimate diameter of a cable or wire depends, of course, upon the number of wrappings which its insulation comprises and the thickness of the outer cotton braiding. This latter serves to protect the real insulating material from mechanical displacement, and is, therefore, only

necessary with cables or with solid wires, if these latter are employed for armature windings. Two or three wrappings of insulation suffice for the magnet windings. As regards the requisite thickness of cotton braiding, the following table may be consulted.

Diameter of the Bare Wire, *d*.	Number of the Yarn Thread.	Double Thickness of the Insulation in Millimetres.		
		Single Wrapping.	Double Wrapping.	Triple Wrapping.
1 millimetre	70	0·25	0·50	0·65
	100	0·20	0·40	0·45
5 millimetres	70	0·25	0·40	0·55
	100	0·20	0·30	0·35

A braiding should be about one and a-half to two times the thickness of the insulation wrapping. As already remarked, the insulation of cables and rectangular wires is proportionally somewhat thicker than that of solid round wires. Due allowance must therefore be made for this when applying the figures contained in the above table.

When ordering insulated wire it should be specified that the several wrappings of insulation, together with their protecting cotton braidings, are to be put on at one operation; because in this manner the wire is less twisted and retains its original pliability. The meshes of the braiding must, moreover, be drawn fine and tight.

Many manufacturers impregnate the insulation with a colourless gum. This serves to prevent fraying of the insulation at points near where it has been removed in order to lay the wire bare. Excellent impregnating mediums are found in shellac and a preparation well known in America—*i.e.*, "Standard B, Armature and Field-Coil Varnish" (black), manufactured by the Standard Paint Company. Both invest the insulation with greater ability to withstand carbonisation, as shown by the following experiment, made at the author's suggestion. A complete wire with several wrappings of insulation and cotton braiding was impregnated at different points in its length with shellac and the above-mentioned varnish. Upon heating the wire by means of an electric

current, the unimpregnated portions became carbonised, whilst the impregnated sections remained uninjured.

Example.—Suppose that the electrical data relative to a machine yielding 4,000 amperes at 20 volts with a speed of 220 revolutions is as follows:

Armature diameter	$D = 97.9$.
Armature length	$l = 60.0$.
Number of wires in armature circuit...	$N = 120$.
Number of pairs of poles	$p = 3$.
Half the number of collecting points,	$p_1 = 3$.
Mean length of an armature coil ...	$L = 1.6$ m.

The armature is further assumed to be of the toothed type.

It is required to reconstruct this machine for an output of 700 amperes at 120 volts when running at 250 revolutions. Having regard to the very low saturation of the field in the original machine, we may without hesitation arrange to double that saturation. As a consequence,

$$N_1 = \frac{1}{2} \cdot \frac{220}{250} \cdot \frac{120}{20} \cdot 120 = 320.$$

Allowing a 4 per cent. drop in pressure—that is to say, 4·8 volts when the armature is at its maximum temperature, the requisite section of wire,

$$s_1 = \frac{320 \times 700 \times 1.6 \times 1.2}{60 \times 4.8 \times 4 \times 9} = 41.5 \text{ square millimetres.}$$

This corresponds approximately to a sectional area of a cable 8·2 mm. in diameter bare, or 8·9 mm. insulated. If we execute the winding in two layers, the necessary width of the slots will be about 10 mm., and their depth 20 mm. or 21 mm. The grooves are given a somewhat greater depth than is actually required for taking the conductors; this permits the binding wires to be countersunk flush with the teeth. The diameter of the finished armature is then equal to that of its core.

Verification.—The arc embraced by each pole of the machine has a length of 30 cm.; the air-gap amounts to 0·6 cm.; while the armature E.M.F.—that is to say, the pressure between the brushes + the internal loss in

ohms + the drop of pressure due to armature reactions—may be taken at 130 volts. From this it follows that:

$$B = \frac{130 \times 60 \times 10^8 \times 3}{320 \times 250 \times 3} \cdot \frac{1}{60 \times 30} = 5{,}400.$$

Further, according to equation (26),

$$k_{max} \leqq \frac{20}{4\pi} \cdot \frac{5{,}400 \times 0{\cdot}6}{30} = 173;$$

and, from the data of the machine,

$$k = \frac{320 \times 700}{2 \times 3 \times 97{\cdot}9 \times \pi} = 122;$$

$$\frac{k_{max}}{k} = 1{\cdot}42.$$

Air-Gap.—With smooth armatures the air-gap comprises the following dimensions:

1. Thickness of insulation (paper, calico, etc.), about 1 mm. to 2 mm.

2. Radial depth of the several layers of winding. When wire of round section is employed, this depth is minimised by disposing the winding so that the conductors composing each successive layer coincide with the depressions formed between the conductors of the immediately preceding layer. Taking N_1 as the number of layers, the total depth $= d_1' + (N_1 - 1)\, d_1 \sin 60°$. But it is not customary to overwind armatures with more than two layers, so that

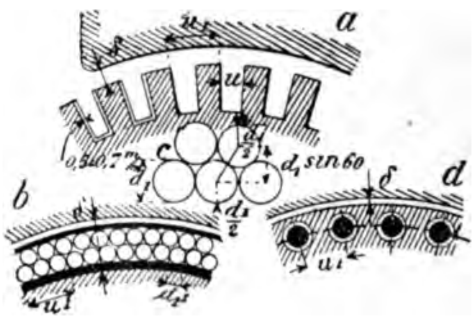

FIG. 47.

$$k = 1{\cdot}9\, d_1.$$

3. Diameter of the binding wire + thickness of insulating bandages, 1·5 mm. to 2 mm.

4. Air-gap proper between the finished armature and pole-pieces, 2 mm. to 5 mm.

Respecting toothed armatures we have the following rule

$$\delta \geqq 0 \cdot 5\, u \text{ (see Fig. 47).}$$

D. Calculations necessary for the Design of an Armature.

To be able to calculate in advance, without great loss of time, the dimensions of a dynamo to be constructed, we must perform two operations:

1. Calculate the approximate dimensions of the armature—diameter and length. 2. Verify this calculation.

First approximation to the exterior dimensions of the armature:

Using equation (10)—

$$E = \frac{N \cdot \phi \cdot n}{60 \times 10^8} \cdot \frac{p}{p_1};$$

wherein
$$N = \frac{k \cdot 2 p_1 D \pi}{C};$$

and
$$\phi = \frac{D \pi \beta l B}{2 p}.$$

$$E = \frac{k \cdot 2 p_1 D \pi}{C} \cdot \frac{D \pi \beta l B}{2 p} \cdot \frac{n p}{p_1 60 \cdot 10^8};$$

whence
$$D = \sqrt{\frac{E C}{n}} \sqrt{\frac{60 \times 10^8}{k \beta B \pi^2} \frac{1}{l}} \quad . \quad . \quad . \quad . \quad (49)$$

For preliminary estimates it will suffice to assume the following values:

$k = 100$ for ring armatures;
$k = 150$ for drum armatures;
$B = 5{,}600$;
$\beta = 0 \cdot 7$.

We are thus enabled to give equation (41) a simpler form—viz.:

For ring windings:

$$D_{cm.} = 39 \sqrt{\frac{E C}{n} \frac{1}{l}} \quad . \quad . \quad . \quad . \quad (50)$$

where l is measured in centimetres.

$$D_{inch} = 9{\cdot}7 \sqrt{\frac{E\ C}{n}\ \frac{1}{l}} \quad . \quad . \quad . \quad . \quad (50)$$

where l is measured in inches.

For drum windings:

$$D_{cm.} = 32 \sqrt{\frac{E\ C}{n}\ \frac{1}{l}} \quad . \quad . \quad . \quad . \quad (51)$$

where l is measured in centimetres.

$$D_{inch} = 7{\cdot}9 \sqrt{\frac{E\ C}{n}\ \frac{1}{l}} \quad . \quad . \quad . \quad . \quad (51)$$

or, assuming $l = \lambda$ D—

For ring windings:

$$D_{cm.} = 11{\cdot}5 \sqrt[3]{\frac{E\ C}{n}\ \frac{1}{\lambda}} \quad . \quad . \quad . \quad . \quad (52)$$

$$D_{inch} = 4{\cdot}5 \sqrt[3]{\frac{E\ C}{n}\ \frac{1}{\lambda}} \quad . \quad . \quad . \quad . \quad (52)$$

For drum windings:

$$D_{cm.} = 10 \sqrt[3]{\frac{E\ C}{n}\ \frac{1}{\lambda}} \quad . \quad . \quad . \quad . \quad (53)$$

$$D_{inch} = 4 \sqrt[3]{\frac{E\ C}{n}\ \frac{1}{\lambda}} \quad . \quad . \quad . \quad . \quad . \quad (53)$$

These formulæ correspond almost exactly with those given by Mr. Albion T. Snell (see *Journal* of the Institution of Electrical Engineers, vol. xix.).

How far they answer to the conditions prevailing in actual practice may be gathered from the comparisons given below:

No.	$\frac{E\ C}{n}$	λ.	Calculated.		Executed.		Remarks.
			D.	l.	D.	l.	
			cm.	cm	cm.	cm.	
1	1·92	0·89	13	11·5	18	16	Bipolar drum.
2	10	1·12	20 7	23·2	24	27	
3	22·2	0·79	30 4	24	31 6	25	
4	57	0·78	41·8	32·6	41	32	4-pole drum.
5	100	0·67	61	41	60	40	Bipolar ring.
6	178	0·45	73·5	33	80	36	6-pole drum.
7	545	0·61	110	67	98	60	6-pole ring.
8	660	0·48	111	53·5	115	55	4-pole drum.
9	2750	0·18	248	45	237	43	24-pole drum.
10	20000	0·34	390	132	320	110	12-pole drum.

We thus see that the formulæ give concordant results for machines of from about 15 kw. to 400 kw. output. In smaller machines it becomes necessary, from purely mechanical reasons, to allow a relatively greater diameter.

Having ascertained the approximate diameter and length, based on the ratio $\lambda = \frac{l}{D}$, we may then proceed to determine the requisite gauge of wire. For a first approximation the following procedure will be found advantageous:

The mean length, L, of one complete loop (in drum windings being equivalent to the length of a single peripheral conductor + that of the connection on one end of the core) is

$$\mathrm{L} = 0{\cdot}019\,(0{\cdot}45\,D + l) = 0{\cdot}019\,D\,(0{\cdot}45 + \lambda) \text{ metres} \quad . \quad (54)$$

where L is in metres, and D and l are given in centimetres. In English measures we shall have L (in feet) $= 0{\cdot}158\,D\,(0{\cdot}45 + \lambda)$, D being given in inches.

Further, according to equations (29) and (47)

$$s = \frac{C}{2\,p_1\,.\,c} = \frac{\mathrm{L}\,.\,N\,.\,C}{200\,.\,p_1^2\,.\,\epsilon\,E}.$$

Substituting the value of N from equation (10), and for ϕ its value $= \frac{D\,\pi}{2\,p}\beta\,l\,B$, this equation then reads:

$$c = \frac{1{\cdot}38\,\beta\,B\,\lambda\,D\,n\,\epsilon}{10^6\,(0{\cdot}45 + \lambda)} \quad . \quad . \quad . \quad . \quad (55)$$

For application in the case of machines destined to run at speeds varying only slightly from the normal, this equation may further be considerably simplified, since $\frac{\lambda\,D\,n}{(0{\cdot}45 + \lambda)}$ is now almost constant, averaging about 17,500. In the case of slow-running dynamos, or where λ is small, it is requisite to reduce this number by from 20 to 30 per cent., or should, on the other hand, large machines with longer armatures be in question, it must be increased about 20 to 30 per cent.

If we suppose that $\beta = 0{\cdot}7$ and $B = 5{,}600$, then

$$c = 90\,.\,\epsilon \text{ (see equation 48)};$$

or, in English measurement,

$$c \text{ per square inch} = 580\,\epsilon;$$

$$s \text{ (in square millimetres)} = \frac{C}{p_1 \,.\, 180\, \epsilon} \quad . \quad . \quad (56)$$

or, in English measure,

$$s \text{ (in square inches)} = \frac{C}{p_1 \,.\, 116{,}000\, \epsilon} \quad . \quad . \quad (56)$$

More Exact Determination.—In order to obtain more accurate figures we should now sketch a small portion of the armature's circumference in outline, either to natural or enlarged scale (see Fig. 47). We then proceed to calculate the number of wires N″ which correspond to a length u_1—

$$N = \frac{D\pi}{u_1} \,.\, N''$$

In toothed armatures the slots are generally either equal or double in number to the commutator sections.

To avoid all possibility of the pole-pieces becoming reversely magnetised, due attention must be given to see that equation (27) is satisfied—that is to say,

$$N < 6{\cdot}37 \,.\, \frac{B_l \,.\, \delta \,.\, p \,.\, p_1}{C\,\beta} > \frac{D\,\pi}{u_1} N'',$$

or, in English measure,

$$N < 2{\cdot}5\, \frac{B_l\, \delta\, p\, p_1}{C\,\beta} > \frac{D\,\pi\, N''}{u_1},$$

where B = induction per square inch, and δ is measured in inches.

At the same time we must not omit to ensure that the saturation of the teeth lies within the necessary limits. In bipolar dynamos this value must not exceed 16,000 to 18,000 lines, whereas when multipolar machines are concerned this value should not exceed 12,000 to 15,000.

By an appropriate modification of the values B, δ, β, N″, and u_1, and changing the sectional area of the wires, it is always possible to fulfil these conditions.

Substituting the values of ϕ and $N = \frac{D\,\pi}{u_1} N''$ in the equation (10), we may calculate the diameter of the armature with sufficient precision by the aid of the equation,

$$D = \sqrt{\frac{E\, p_1\, u_1}{n\, N''\, \beta\, l} \,.\, \frac{120 \times 10^8}{\pi^2 B}} \quad . \quad . \quad . \quad . \quad (57)$$

where E = the induced E.M.F.

Verification.—After the foregoing calculations have been completed, a verification of the several dimensions is indispensable. The size of the wire to be employed must first be determined, which may be done from the dimensions given in the design. Similarly we must assure ourselves that there will be sufficient room for the end connections, etc.

Example 1.—Let it be required to determine the necessary armature for a four-pole drum machine yielding 100 kw. (125 volts, 800 amperes) at a speed of 400 revolutions:

$$p_1 = 2;\ \lambda = 0{\cdot}6;\ \epsilon = 0{\cdot}03 \text{ (3 per cent. loss)};\ \beta = 0{\cdot}7.$$

According to equation (53)

$$D = 10 \sqrt[3]{\frac{100{,}000}{400} \cdot \frac{1}{0{\cdot}6}} = 75 \text{ centimetres};$$

$$l = 0{\cdot}6 \times 75 = 45 \text{ centimetres};$$

while, according to equation (56),

$$s = \frac{C}{p_1 \times 180 \times \epsilon} = \frac{800}{2 \times 180 \times 0{\cdot}03} = 74 \text{ square millimetres.}$$

(See Fig. 48.)

Further, according to equation (27),

$$N = \frac{D\,\pi\,N''}{u_1} < 6{\cdot}37 \frac{B\,\delta\,p_1\,p}{C\,\beta};$$

or,

$$\frac{75\,\pi}{1{\cdot}7} < \frac{6{\cdot}37\,B\,\delta\,.\,2 \times 2}{800 \times 0{\cdot}7}.$$

Selecting the values B = 6,000 and δ = 0·6 cm., we obtain on the left side of this equation 138, and on the right side 164; therefore

$$\frac{k_m}{k} = 1{\cdot}19.$$

and, according to equation (57),

$$D = \sqrt{\frac{132 \times 2 \times 1{\cdot}7}{1 \times 0{\cdot}7 \times 45 \times 400} \cdot \frac{120 \times 10^8}{\pi^2\,6{,}000}} = 84 \text{ centimetres.}$$

The diameter given by formula (53) was consequently somewhat too small; for this diameter $\frac{k_m}{k} = 1{\cdot}06$. Thus it is sufficiently evident that the employment of toothed armature

cores is limited by the output of the machine, and depends also on the number of poles. In order, for instance, to prevent a reversal of the magnet poles by the armature reaction we are obliged to allow a very considerable air-gap, thereby forfeiting one of the advantages of the teeth—*i.e.*, that constituted in being able to reduce the air-gap, and, consequently, also the number of ampere-turns in the field winding. By slightly enlarging the pole-shoes, the machine in question might almost to equal advantage be provided with a smooth armature. However, by modifying the machine for a six-pole field, we are enabled not only to retain the toothed type of core, but also to secure at the same time its full advantages.

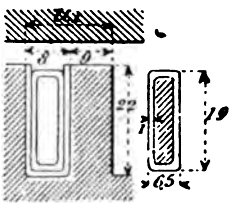

FIG. 48.

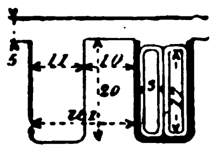

FIG. 49

Example 2.—Modification of the machine described in Example 1 for six poles and six brushes, assuming that the armature length (45 cm.) remains unchanged:

$$s = \frac{800}{3 \times 180 \times 0{\cdot}03} = 50 \text{ square millimetres in round figures.}$$

$$\beta = 0{\cdot}7\ ;\ u_1 = 2{\cdot}1 \text{ (see Fig. 49).}$$

$$N = \frac{84 \times \pi \times 2}{2{\cdot}1} < 6{\cdot}37\ \frac{B . \delta . 3 \times 3}{800 \times 0{\cdot}7}.$$

Further, let $B = 5{,}500$ and $\delta = 0{\cdot}5$; then

$$D = \sqrt{\frac{132 \times 3 \times 2{\cdot}1}{2 \times 0{\cdot}7 \times 45 \times 1{,}100} \cdot \frac{120 \cdot 10^8}{\pi^2 . 5{,}500}} = 85 \text{ centimetres.}$$

Corresponding to this diameter $\frac{k_m}{k} = 1{\cdot}1$.

We are thus enabled—quite apart from the other advantages of six-pole machines (such as a saving in weight)—

to reduce the air-gap to a minimum, and thereby effect a saving of about 24 per cent. in the ampere-turns, which would otherwise have been requisite.

Calculation of the Interior Diameter of an Armature.—When drum armatures are in question, the interior diameter of the core depends entirely upon the value of ϕ, but with Gramme rings, on the other hand, the possibility of placing the interior wires must be considered. As a consequence, ring machines have a comparatively greater armature diameter, especially in the case of small machines.

After the value of ϕ has been computed from the dimensions and winding, we may ascertain the inner diameter of the armature by assuming various saturations, B_a, for the core, and then calculating, according to the method given in equation (34), the corresponding watts lost through hysteresis. The following approximate figures might, for instance, be taken:

For two-pole machines B_a = 14,000 to 16,000.
,, four- ,, ,, B_a = 12,000 to 14,000.
,, six- ,, ,, B_a = 9,000 to 12,000.

It may also be mentioned that with toothed armatures it is usual to disregard the teeth and only reckon as permeable that area of the core contained between the bottom of the notches and the inner surface of the armature. When, therefore, we write

$$\tau = \frac{D_1}{D'} = \frac{\text{Interior diameter}}{\text{Exterior diameter}}$$

it is always to be understood that D′ denotes the diameter measured between the bases of the teeth. The direct calculation of D_1 is likewise rather complex, but may be facilitated by employing the tables given at the end of this book (Chapter XII.).

By substituting in equation (34) the values of:

$$B = \frac{\phi}{D'^2 (1 - \tau) \, 0{\cdot}9 \, \lambda};$$

$$\eta = 0{\cdot}003;$$

and

$$V = \frac{D'^3 \pi}{4} (1 - \tau^2) \, \lambda \, . \, 0{\cdot}9,$$

we obtain the formula:

$$\frac{(1 - \tau)^{0.6}}{1 + \tau} = \frac{2.5}{10^{10}} \frac{\phi^{1.6}}{D'^{0.2}} \frac{1}{\lambda^{0.6}} \frac{\omega}{w_k} = A \quad . \quad . \quad (58)$$

We proceed now to work out the middle term of this equation, employing Table VII. This operation gives us the value of m, enabling us thereby to obtain the corresponding value of τ from Table VIII. Approximately speaking $\tau = 1 - A$.

Example.—Given a permissible loss of 1,200 watts (1·2 per cent.), what interior diameter must be allowed for the six-pole machine dealt with in the previous example?

$$\phi = \frac{132 \times 60 \times 10^8}{400 \dfrac{85\ \pi^2}{2.1}} = 7,800,000;$$

$$D' = 85 - 4 = 81;$$

$$\lambda = \frac{45}{85 - 4} = 0.55.$$

$$1.6 \log 7,800,000 = \log (10.65 \times 10^{10});$$

$$0.2 \log 81 = \log 2.41.$$

$$\lambda^{0.6} \text{ (according to Table VIII.)} = 0.697;$$

$$\omega = \frac{400 \times 3}{60} = 20;$$

$$A = \frac{2.5}{10^{10}} \frac{10.65 \times 10^{10}}{2.41} \cdot \frac{1}{0.697} \cdot \frac{20}{1,200} = 0.264.$$

Referring again to Table VIII., we find that corresponding to this value $\tau = 0.73$. It is also to be remarked here that $1 - A = 1 - 0.264 = 0.736$, and, therefore, agrees fairly closely with the value of τ determined from the table.

From the above we calculate:

$$D_1 = 0.73 \times 81 = 59 \text{ centimetres.}$$

Denoting by τ_1 the ratio borne by the internal diameter, D_1, to the external diameter, D, of the armature, the latter

measured from the crowns of the teeth, we may tabulate as follows the approximate values holding good in practice.

Number of Poles.	τ_1
2	0·3 to 0·4
4	0·6 to 0·65
6	0·65 to 0·7
8	0·75 to 0·8
10	0·78 to 0·83
12	0·80 to 0·85
24	0·9

These figures relate to machines actually constructed of from 2 h.p. to 2,000 h.p.; the larger values of τ_1 refer to the larger machines. In the calculation for a six-pole machine just worked out, our figures were D = 85 centimetres; $D_1 = 59$, and as $\frac{D_1}{D} = \frac{59}{85} = 0{\cdot}7$ in round numbers, it will be seen that the agreement with the table is fairly close.

In conclusion, we insert another table containing the dimensions, etc., relative to armatures of various makes. It is not suggested that the figures contained therein should represent finality or be employed indiscriminately as bases for new construction. Although a greater part of the machines quoted may possess undoubted merits—for which the names of their respective manufacturers offer, indeed, a certain guarantee—yet the list also includes machines which quite as indisputably leave room for improvement. The table is intended to serve merely as an aid by which the approximate dimensions of a machine may be quickly determined, and for purposes of comparison. Those who understand the art of designing will also be able to derive many interesting conclusions from the figures given.

TABLE CONTAINING THE DIMENSIONS AND

Number	Specific Output in Kilo-watts.	Normal Output	Volts.	Speed.	p	p_1	Armature.			
							D cm.	l cm	N.	Wire.
1	0·42	1 h.p.	110	1 750	1	1	13·3	13·3	768	—
2	0·75	1·5 kw.	100	2,000	1	1	15	15·6	200	1·8
3	2·4	5 h.p.	110	1 550	1	1	20·9	20·4	348	—
4	4·16	5 kw.	110	1 200	1	1	20	20	228	2·5
5	5·35	7·5 ,,	100	1 400	1	1	27·6	28	165	3·8
6	5·4	10 h.p.	220	1 360	1	1	23·5	23·4	576	—
7	11	20 ,,	220	1 350	1	1	29·6	29	320	—
8	15·6	14 kw.	125	900	1	1	30	26	180	4
9	25	20 ,,	100	800	1	1	42	42	144	19 wires of 1·6 mm
10	27	21 ,,	105	780	1	1	28·2	19	120	30 sq. mm.
11	38	35 h.p.	440	675	1	1	38·4	36·2	464	—
12	57	40 kw.	125	700	2	1	41	32	122	3 × 18
13	63	30 h.p.	500	350	2	1	29·5	38	760	2·3
14	66·6	40 kw.	100	600	1	1	51·4	40	80	9·2
15	83	50 ,,	125	600	2	2	56	36	224	2 × 16
16	83·4	50 ,,	125	600	2	2	58	27	210	—
17	100	60 ,,	110	600	2	2	50	38	160	6 × 6
18	114	75 h.p.	440	675	1	1	50	47	38·8	—
19	120	60 kw	120	500	1	1	62·2	40	140	22 × 4
20	148	74 ,,	530	500	3	1	80	33	400	1 × 25
21	160	72 ,,	125	450	2	2	63	44	176	3 × 18
22	330	66 ,,	200	110	2	2	105	31	516	—
23	666	200 ,,	530	300	2	2	115	55	488	1·6 × 18
24	900	360 ,,	600	400	2	2	122	63·5	360	—
25	2740	410 ,,	55	150	12	12	237	43	432	19 wires of 2·8 mm.
26	20000	1500 ,,	550	75	6	6	320	110 (about)	1392	6·35 × 19

WINDINGS OF ARMATURES OF DIFFERENT TYPES.

Commutator.		δ cm.	ϕ	Observations.
N_2	Length cm.			
24	—	—	489,000	Sprague (Manchester type)
40	4	0·14	1,570,000	Oerlikon, old form (Manchester type)
38	—	—	1,228,000	Sprague
38	8	—	2,560,000	Soc. anonyme d'électricité (formerly Lahmeyer)
55	6	0·175	2,800,000	Oerlikon old type
48	—	—	1,800,000	Sprague
80	—	—	2,974,000	Sprague
45	15	0·5	5,000,000	J. Farcot
72	13	0·10	5,700,000	Oerlikon, old type
60	—	1·05	7,153 000	Gisbert Kapp
58	—	—	8.517,000	Sprague
61	16·4	0·6	4.750 000	Oerlikon
95	7·5	0·555	5,200,000	Westinghouse Company (tramway motor)
40	21	—	13,800 000	Oerlikon old type
112	—	0 75	6 000,000	J. Farcot
105	14·5	—	6 400,000	General Electric Company
80	18·5	—	7,500,000	Schuckert
97	—	—	13,430,000	Sprague
70	22	0·5	11 000,000	Oerlikon, old type
200	12	—	5,700,000	Alioth, Basle
88	18	0·8	10,000,000	Oerlikon
516	34	—	22 600,000	Siemens and Halske
244	23	1·0	23 400,000	Oerlikon
180	38	—	27,000,000	General Electric Company
216	35	2·45	5,600,000	Oerlikon
696	50·4	0·635	35,000,000	General Electric Company

CHAPTER III.

THE DESIGN OF THE FIELD MAGNETS.

A. Characteristic Properties of Different Magnet Windings

The simplest means by which one can obtain a clear insight into what actually goes on in a dynamo, consists in graphically plotting its characteristic—a method which was first employed by Faraday, and has since found universal favour. One should, moreover, never neglect to keep a graphic record of all test results, for it is only possible in this manner to verify data, or detect the results of unavoidable errors, and distinguish these from faults of construction which may be remedied.

The ordinary system of co-ordinates is utilised for this purpose, and it is customary in plotting values which are to be compared—excitation with pressure, pressure with speed, etc.—to represent the pressures as ordinates, and the corresponding speeds, or if required, the ampere-turns (or simply the amperes) as abscissæ.

Although, strictly speaking, the term "characteristic" applies only to curves exhibiting the relation between armature current and terminal voltage, yet the expression is frequently employed in reference to curves generally. Of these curves, by far the most important is that one which affords a means of comparison between magneto-motive force (C_m N and pressure. We might call it the "curve of magnetisation." Its peculiar value lies in that at any time the characteristic proper may, with ease, be deduced from it. Instead of representing by the ordinates the terminal pressure or the induced E.M.F., it is more advantageous to substitute the total induction, ϕ, computed by means of equation (10). We thereby become not only independent of the revolutions, but also of the number of inductors contained in the armature winding—a simpli-

fication which will frequently prove convenient in later calculations.

Fig. 50 depicts such a curve of magnetisation, which will serve for any separately-excited machine running on open circuit. As will be observed, the curve at its outset is very nearly straight, until a certain point is reached, where it bends rapidly and then finally resolves itself into a straight line inclined at a small angle to the horizontal axis. *That is to say, the lines of induction increase at first almost in proportion to the strength of the exciting current, but afterwards approximates more and more nearly to a maximum value.* The field of an arc-lighting dynamo should be neither too weakly nor too strongly saturated. The former condition conduces to instability of the brush pressure, considerable fluctuations arising with the least variation of speed, while the disadvantage of too dense a field is only a question of relative cost. In order to keep the initial cost of a machine within limits, and at the same time avoid the first-mentioned defect, the following rule should be observed:

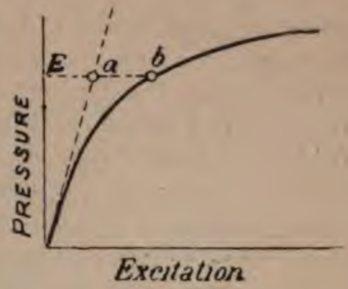

FIG. 50.

If we continue the first straight portion of the characteristic (Fig. 50) until it cuts the straight line E b drawn parallel to the axis of abscissæ at the vertical distance E (E.M.F.) in a, then the distance a b should be approximately equal to E a, but in no case should it be shorter than E a.

This rule, as will become apparent later on, may also be expressed as follows: The total number of ampere-turns in the field magnets should be at least twice as great as would overcome the resistance of double the air-gap.

Arc-lighting machines and series-wound motors provide exceptions to this rule. In these cases it is advantageous to employ the strongest possible saturations.

The Series Machine.

In the series-wound type of machine, as shown in Fig. 51, the whole current generated in the armature circulates through

the field windings in accordance with Ohm's law. A lowering of the external resistance consequently produces an immediate increase of current; and as this means correspondingly increased excitation, the pressure, of course, also rises. It is for this reason that series-wound dynamos are not well adapted for employment with incandescent lamps requiring constant pressure; whilst, on the other hand, they are eminently adapted for running on arc-light circuits, or those supplying incandescent lamps mounted in series. For the latter purpose it is, however, requisite that the machine should maintain a constant current strength, whilst with a varying number of lamps in series the necessity arises for corresponding adjustments of the pressure. Various methods are in vogue for effecting this purpose, but they may all be divided into three comprehensive groups, as follows: (1) regulation of pressure through adjustment of the magnetic field; (2) regulation by shifting the brushes (this method is only applicable with machines possessing feeble armature reaction and a relatively large number of commutator segments, for otherwise sparking would be too violent); (3) regulation by adjusting the number of revolutions to produce the voltages required.

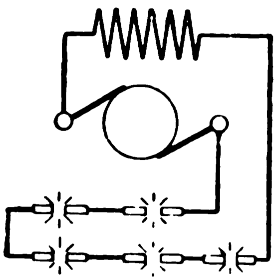

Fig. 51.

Looked at from an economical point of view the last method would appear to be the best, though it would appear to have found but little application in practice. While upon this subject, attention may be directed to a very interesting lecture delivered by A. Bernstein before the Elektrotechnische Verein, Berlin, on October 22, 1889. (See *Elektrotechnische Zeitschrift* for November, 1889.)

A. Bernstein pointed out that a constant current might be maintained in an installation of electric lamps arranged in series, with a series-wound dynamo as a source of supply, by dispensing entirely with the governor of the driving engine, as the engine then works at a constant piston pressure. The following phenomena occur when a portion of the lamps are switched off: In the first place, the resistance of the

external circuit is decreased; at the existing pressure the current would therefore increase, requiring at the same time an extra expenditure of energy on the engine's part. But as there is no reserve of steam pressure, this extra demand necessarily reacts upon the engine, decreasing its speed, but only to that extent which is sufficient to balance the current.

The consideration of the series-wound dynamo in its use as a generator for arc lamps connected in series, constitutes the contents of a separate chapter. We will now pass on to the consideration of this type of machine in its capacity as a transmitter of energy. It will be of especial interest to acquaint ourselves with the conditions under which a constant speed of the secondary machine is attainable with a variable load.

The internal pressure of the primary machine might, as previously, be computed by means of the formula—

$$E = \frac{n \phi N}{60 \times 10^8} \cdot \frac{p}{p_1}.$$

For the sake of simplicity this may be written

$$E = K \,.\, n \,.\, f\,(C\ N_m).$$

If R represents the sum of the resistances of the generator and the motor (armatures and magnets), together with that of the connecting leads, there will remain at the terminals of the secondary machine an effective pressure,

$$E_1 = E - C \,.\, R = K \,.\, n \,.\, f\,(C\ N_m) - C\ R,$$

or, as E_1 may also be written $K_1 \,.\, n_1 \,.\, f \,.\, (C\ N'_m)$, the speed of the motor may be expressed by

$$n_1 = \frac{E_1}{K_1 f\,(C\ N'_m)} = \frac{K\, n f\,(C\ N_m)}{K_1 f\,(C\ N'_m)} - \frac{C\ R}{K_1\ f\,(C\ N'_m)}.$$

The simplest case would be where the two machines are complete duplicates of one another, both as regards construction and winding—that is to say, when

$$K_1 = K;\ \ N'_m = N_m;\ \ f\,(C\ N'_m) = f\,(C\ N_m).$$

Further, assuming that both machines are to be worked with a degree of saturation not exceeding the limit represented by the straight portion of the characteristic (Fig. 50),

it follows that f (C N'_m) might also be written $K_2 \,.\, C$, and equation (51) might be more simply expressed as follows:

$$n_1 = n - \frac{R}{K_1 \, K_2} = n - K_3 \quad . \quad . \quad . \quad . \quad (60)$$

That is to say, the secondary machine should theoretically maintain a constant speed as long as n (which represents the speed of the primary machine) remains constant, however the load is varied, provided that its saturation remains within the limit represented by the straight part of the characteristic. Practice does not, however, always conform to this theory, because, as we shall see later on, the reaction of the armature currents on the magnetic field often constitutes a factor which must not be neglected. In the primary machine it tends, as a matter of fact, to weaken the magnetic field, but it strengthens that of the secondary machine. Thus, the armature reaction in the motor does not counteract that of the generator, but the two effects sum themselves up. Having regard to this fact, it is always advisable to allow a slightly increased length of winding for the generator magnets, whilst the motor's field winding should be shortened by a corresponding amount. Moreover, attention must naturally be directed to remove as far as possible the cause of this disturbance by proper construction of the machines (see Chapter VI.).

If the two machines are required to run at equal speeds, the only change necessary is a modification of the constants K and K_1. In that case we may write

$$n_1 = \frac{K}{K_1} \,.\, n - \frac{R}{K_1 \,.\, K_2};$$

$$n_1 = n.$$

From this it follows—

$$n = \frac{K}{K_1} \,.\, n - \frac{R}{K_1 \,.\, K_2};$$

or,

$$K_1 = \left(K \,.\, n - \frac{R}{K_2}\right) . \frac{1}{n}.$$

The foregoing formulæ, as already remarked, are only applicable provided that both machines are to work on the straight portion of their characteristics. If, now, we consider the case most often met with in practice, in which

the primary and secondary machines, although similar as regards construction and winding, yet work with different degrees of saturation, equation (60) will then read—

$$n_1 = n - \frac{C\,R}{K\,f\,(C\,N'_m)} \quad . \quad . \quad . \quad . \quad . \quad (61)$$

The numerator of the fraction increases in proportion to the strength of current supplied, whilst a reference to Curve 50 shows us that the f (C N'_m) no longer rises in proportion to the current strength. As a consequence, the fraction no longer remains constant, but rises steadily with an increasing value of C—that is to say, the secondary machine will run with less and less speed as the load is increased.

It still remains for us to consider what further modifications will result in the case where the motor and the generator differ both in form and degree of saturation. A graphic delineation of the equation $E_1 = E - C\,R$ may easily be obtained by plotting the internal characteristic of the primary machine together with the straight line C R. As, however, the drop of pressure in the secondary machine is still an unknown quantity, we will base our calculation on a permissible limit, which we will endeavour subsequently to attain by a suitable design of the winding.

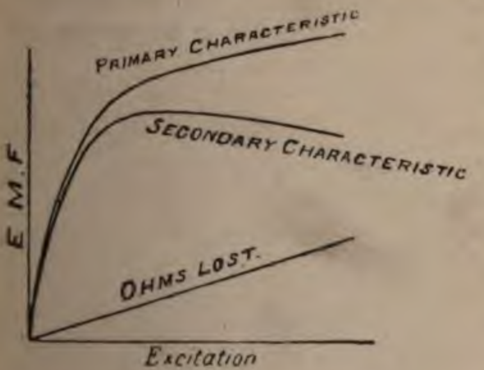

FIG. 52.

When the losses in the leads are relatively great, it is of little consequence if the other losses found in practice differ slightly from those previously obtained from calculation.

In order to allow for the influence of the armature reaction, the calculation of which is extremely complicated, it will at present suffice in most cases to estimate the total loss at double the loss due to the armature resistance.

If the ordinates of the primary characteristic be diminished

by the corresponding magnitudes, C , R, we shall obtain a new curve, termed the *secondary* or internal *characteristic* (see Fig. 52). Consequently, the motor may be dealt with by a method similar to that applied to the generator; it will suffice to determine how the ordinates of the characteristic and those of Curve III. can be made to correspond for the same current strength (not the same number of ampere-turns).

A rapid comparison of the two Curves I. and III., makes it at once evident that constancy of speed in the secondary machines can only be obtained, even when high saturations are employed, when the average degree of saturation in the motor is higher than that in the generator. Due to this favourable circumstance, we may give slightly smaller dimensions to the motor than to the generator. Further, when the load variations are inconsiderable, it is naturally only requisite that the secondary characteristic should coincide with Curve III. at those points between which the actual fluctuations in the current occur, whilst the remaining parts of the curves may take quite different courses.

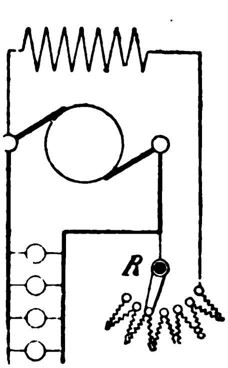

FIG. 53.

For the rest, the secondary characteristic must not curve too sharply, because abrupt bends are only attainable with the co-operation of a strong armature reaction, a condition which is very apt to induce violent sparking at the brushes.

The Shunt-Wound Machine.

(See Fig. 53.)

The current flowing at any time through the magnet windings is expressed according to Ohm's law—

$$C_m = \frac{E}{R},$$

where R represents the collective resistance of the magnet coils connected in series between the two brushes.

As in this type of machine the exciting current is comparatively independent of the external circuit, it naturally follows that with constant armature speed the pressure between the brushes (apart from a relatively slight drop of voltage in the armature, due to the combined effects of resistance and armature reactions) will vary only within relatively narrow limits. This feature renders this type of machine particularly suitable for installations where the total resistance of the external circuits is relatively small. Shunt-wound machines possessing high armature resistances constitute exceptions to this rule.

Before entering into calculations for shunt winding, we will symbolise the necessary values respectively as follows:

Let $C_m N_m$ = requisite number of ampere-turns per magnet coil;
s = cross-sectional area of the magnet wire;
L = mean length of a single turn of the magnet windings;
E = pressure between the brushes;
N_m = number of turns per coil;
N'_m = number of magnet coils connected in series;
C = total armature current, and
$C_m = \epsilon C$ = current flowing through the magnet windings ($100 \,.\, \epsilon$ = per cent. loss); consequently

$$C_m = \frac{E}{R} = \frac{E}{N_m N'_m \,.\, \frac{L}{60 \,.\, s}}.$$

From this the value of s may be computed; but in consequence of the increase of resistance with the rise of temperature, about 20 per cent. must be added to the calculated result. Then

$$s = \frac{(C_m N_m) N'_m L}{E\,50} \quad . \quad . \quad . \quad . \quad . \quad (62)$$

This formula, it may be observed, also holds good for series machines.

Further, as $C_m = s \,.\, c$, we can also write

$$N_m N'_m L = \frac{E\,50}{c} \quad . \quad . \quad . \quad . \quad . \quad (63)$$

wherein the total length of wire is indicated on the left.

$C_m\ N_m$ denotes the number of ampere-turns per magnet, and is, therefore, initially determined, as is likewise the case with regard to E (the pressure between the brushes), while L is only ascertainable from the structural dimensions of the machine, and must be estimated approximately.

Since it is advantageous, in order to avoid the use of two thin wires, to arrange all the coils in series (N'_m being then equal to the total number of coils), s preserves a definite value for every machine, quite independent of the respective exciting current strengths. We have now only to determine the number of the turns per coil—

$$N_m = \frac{C_m\ N_m}{\epsilon\ C} = \frac{C_m\ N_m}{C_m} \quad . \quad . \quad . \quad . \quad (64)$$

Example 1.—A small machine with a terminal pressure of 25 volts requires an excitation of 2,500 ampere-turns per magnet coil. Let the mean length of a turn be $L = 0{\cdot}64$ m., then the two coils being connected in series $N'_m = 2$. What must be the diameter of the wire?

According to equation (62):

$$s = \frac{C_m\ N_m\ .\ N'_m\ L}{E\ .\ 50} = \frac{2{,}500 \times 2 \times 0{\cdot}64}{25 \times 50} = 2{\cdot}56 \text{ sq. mm.}$$

The diameter corresponding to this section, according to Table II. (at the end of the book) = 1·8 mm.

Example 2.—It is required to so proportion the shunt winding of a two-pole machine, giving an output of 250 amperes at 5 volts pressure, that the shunt current does not exceed about 7 per cent. of the total current generated. How must we proceed?

Let $C_m\ N_m = 4{,}300$, and $L = 0{\cdot}5$ m. The two magnet coils being connected in series, $N'_m = 2$.

According to equation (62):

$$s = \frac{4{,}300 \times 2 \times 0{\cdot}5}{5 \times 50} = 17{\cdot}2 \text{ square millimetres.}$$

Further, equation (56) gives us:

$$N_m = \frac{C_m\ N_m}{\epsilon\ .\ C} = \frac{4{,}300}{0{\cdot}07 \times 250} = 246 \text{ turns per magnet coil.}$$

In connection with the foregoing remarks, there remains

still another question for consideration—viz.: What effect would be obtained if we arranged the two magnet coils of a two-pole machine in parallel instead of in series?

A solution may easily be obtained.

Denoting by r the resistance of a single magnet coil, then for series connection

$$R = 2 \cdot r,$$

whereas for parallel connection

$$R = \frac{r}{2}.$$

The total flow of current through the magnet windings would, therefore, be $\frac{2 \cdot r}{\frac{r}{2}}$ = four times as great in the latter as compared with the former case; and since this total current flow is divided equally between the two coils, we obtain as resultants:

$$\text{Ampere-turns} = \frac{4\ C_m}{2}\ N_m = 2\ C_m\ N_m.$$

Under certain conditions this method might be employed as a makeshift, should a machine, during its test, prove of too low a voltage. Such a procedure is, however, always a doubtful remedy, and for this reason too much care cannot be bestowed upon calculations relative to the shunt windings, since unwinding the coils after the machine has once been constructed will entail much expense and loss of time. On the other hand, a possible heating of the magnets might be remedied by adding more turns in series with the original coils.

For the charging of accumulators, shunt-wound dynamos are almost exclusively employed. It is always advisable when putting down plant for accumulator charging to insert a minimum-current cut-out in the main circuit, so that the connection between the dynamo and accumulators may be automatically broken should the current generated by the machine sink below a certain minimum value. An example will show the advantage of such an arrangement.

Let us suppose that from some cause or other the dynamo belt should slip off the driving pulley; a back current from

the accumulators will at once result. If the dynamo happens to be running at full speed at the time, this will, indeed, have no detrimental effect, the machine then simply continuing to run as a motor with the same direction of rotation. Should, however, the contrary be the case, which is perhaps the most probable contingency, then the battery of accumulators will be short-circuited through the extremely low resistance of the almost stationary armature, and thus exposed to injury. This action of the battery might, indeed, be prevented by the insertion of protecting fuses in the circuit, though this method does not always suffice to prevent a reversal of the magnet poles—a phenomenon which the author has often observed with machines of the well-known Manchester type. This fact would appear in the light of a contradiction to the theory of shunt-wound dynamos, in so far as the magnetising current has the same direction of flow in either case.

The explanation is manifestly attributable to the fact that through the short-circuiting of the battery through the machine, and consequent sudden increase of current carried by the armature, a reversed current is induced in the field-magnet coils. Besides this the original exciting current naturally decreases as a simple consequence of the diminished pressure; the magnetic field at last vanishing entirely, or even becoming reversed by virtue of the current induced by the variation of the armature current.

The employment of a single machine for charging purposes is always attended with certain disadvantages. Thus, since the voltage of the accumulators rises towards the end of the charging process by about 35 per cent., the dynamo must necessarily be designed for this maximum pressure, and is, therefore, during most of the time of charging, very weakly saturated, a condition which is liable to cause sparking. For this reason, supplementary machines, or boosters, are employed in nearly all large central supply stations working with accumulators. These boosters are arranged so that they may be switched in series with the principal generators, and thus, when required, made to furnish the additional pressure requisite to complete the charging operation. But, as at the same time with the increase of back pressure from the accumulators a corresponding decrease

of the charging current must perforce occur, it becomes evident that the boosters may be designed for a somewhat smaller current capacity than the primary machines.

Regulation of the Exciting Current in a Shunt-Wound Machine.—An inspection of the equation $C_m = \frac{E}{R}$ makes it obvious that by inserting a variable resistance in the shunt circuit of a dynamo we are enabled to modify C_m, and consequently also the terminal pressure of the machine, at our pleasure. As, however, the latter is not proportional to the exciting current, C_m, the necessary value of such resistances or rheostats, which, unless under special circumstances, are generally designed for controlling from 5 to 10 per cent. of the total pressure, depends principally upon the degree of saturation of the particular machine in question, and will therefore be greater in proportion as the saturation is greater.

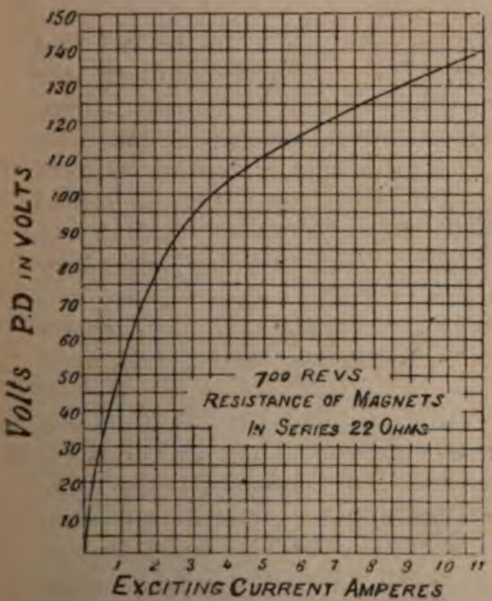

FIG. 54.

Example.—Let Diagram 54 represent the magnetisation curve of a lighting machine with a terminal pressure of 110 volts at a constant armature speed (700 revolutions per minute), the resistance of the magnet coils in series being 22 ω.

It is required to design a regulator which will enable us to maintain the machine's voltage constant, notwithstanding a speed variation of about 28 per cent. (14 per cent. above and 14 per cent. below the normal). How must we proceed

to calculate the necessary resistance? For the time being we will disregard the armature resistance.

It is obvious that, with constant excitation, the pressure of the dynamo will rise or fall in proportion as the armature revolutions are respectively augmented or decreased. On the one hand, we have $1{\cdot}14 \times 700 = 800$, and on the other, $0{\cdot}86 \times 700 = 600$ revolutions. In order, therefore, to maintain the original tension of 110 volts, with the revolutions at 14 per cent. above the normal, the excitation must be so far reduced that the corresponding pressure multiplied by the ratio $\frac{800}{700}$ still gives 110 volts as resultant—that is, we seek the exciting current corresponding to $110 \times \frac{700}{800} = 96{\cdot}4$ volts. This is $3{\cdot}1$ amperes.

At normal speed the excitation equals 5 amperes, and at 600 revolutions $\left(110 \cdot \frac{700}{600} = 128 \text{ volts}\right)$, it will equal $8{\cdot}3$ amperes.

Assuming that at 600 revolutions the whole of the resistance is switched out, it follows that the resistance offered by the magnet winding should be equal to

$$\frac{110}{8{\cdot}3} = 13{\cdot}3\ \omega,$$

and the regulating resistance should be equal to

$$R_1 = \frac{110}{3{\cdot}1} - 13{\cdot}3 = 22\ \omega.$$

The above process presupposes that the armature carries no current. If the dynamo is loaded, and if we are to take account of the consequent fall of pressure, the conditions will differ entirely. Let us suppose, for instance, that the fall in pressure at full load amounts to 8 per cent. The requisite E.M.F. would then be $\frac{110}{0{\cdot}92} = 120$ volts at 700 revolutions; $120 \cdot \frac{700}{600} = 140$ volts at 600 revolutions; or $110 \cdot \frac{700}{800} = 96$ volts at 800 revolutions and light running; the corresponding exciting currents being respectively 6·6, 11,

and 3·1 amperes. Consequently, the permissible resistance of the magnets $= \frac{110}{11} = 10\ \omega$, while that necessary for the rheostat coils $= \frac{110}{3 \cdot 1} - 10 = 25 \cdot 5\ \omega$.

It may be mentioned here that the above example is only intended to illustrate the method of calculating. Such fluctuations of speed would, as a matter of fact, scarcely be met with in general practice.

It is clear from the foregoing that the exciting current varies between 3·1 and 11 amperes, which means that the rheostat with its maximum resistance switched in must be capable of continuously carrying a current of 3·1 amperes, while the last coils should be of sufficient capacity to carry 11 amperes for an indefinite time.

Since the resistance of the magnet winding increases with the rise of temperature, it follows that the current flow correspondingly decreases, and hence the necessity, when starting the machine on a load, of switching a certain resistance into the magnet circuit which will have to be gradually switched out again as the temperature rises, even without additional load coming on.

Automatic regulators are often employed where great variations of speed occur, and to compensate the fall of pressure arising from armature loss and armature reaction. Similarly, where traction plants are running in parallel with accumulators, it was formerly a general rule to provide the latter with an automatic regulator. Experiments which were conducted jointly by the Oerlikon engineering establishment and the Haagen accumulator works relative to such installations showed, however, that up to a certain point a similar result might be obtained by dispensing entirely both with the electrical and engine regulators.

Respecting the traction plant installed at Zürich for running the electric street railway there (the first installation, by the way, worked from accumulators at a central station) the automatic regulation has been given up.

Running Shunt-Wound Dynamos in Parallel.—In installations comprising two or more units it is customary to run them all in parallel, for the following reasons: (1)

To balance as nearly as possible the unavoidable variations in speed to which the driving motors (steam-engines, etc.) are liable; and (2) in order, in the event of the disablement of one machine, to be able to transfer and distribute its load evenly between the remaining machines, without interrupting the supply.

A method frequently employed in earlier practice when an additional machine was to be switched in parallel, was to run it up on a so-called lamp battery, or let it work at first on a variable resistance. Fig. 55 represents such an arrangement: A A are the ampere-meters, and V the voltmeter.

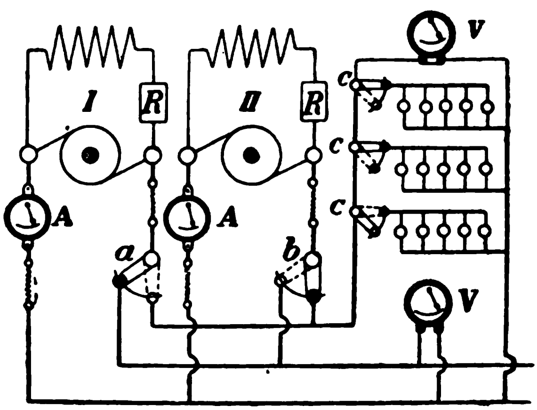

FIG. 55.

Let us suppose that machine I. is already working, and machine II. is required to be put in parallel. It is obvious that before machine I. could have been run up separately on the 'bus bars, the contact lever, *b*, must have been thrown over so as to break connection between machine II. and the external circuit. In such a position it may complete the circuit to the lamp battery. We now start the second machine, bringing it up gradually to full speed, then switch in successive instalments of the lamp battery and adjust the excitation by means of the hand regulator, R, until the voltage and load of the machine are equal to those of machine I. This may be determined by observing the voltmeter and the two ampere-meters. When this has been accomplished, the two machines may be connected in parallel by pulling over

lever *b*, but attention must subsequently be given to keep the load evenly balanced. Such a lamp battery is, however, by no means indispensable; on the contrary, the same end may be attained in a simpler manner, for instance, by running up the speed of the new machine on open circuit until it has attained a suitable value, at the same time adjusting the pressure to be 1 to 2 volts less than that of the machine already on load. We then close switch *b* (Fig. 56), afterwards regulating the shunt resistance until either machine is taking its fair portion of the load as indicated by the ampere-meters. With due care in performing the operation, a rise of pressure may be entirely avoided.

Experience has proved that shunt-wound machines with very low saturation will not run well in parallel. It is likewise inadvisable to run machines of different outputs and field strengths upon a common network of mains which is subject to great and sudden load variations. Trials which were conducted some years ago at one of the tramway central depôts of Baltimore (Maryland) only succeeded, according to the reports of the resident engineer, after the two machines in question had been modified until their characteristics exactly corresponded within the limits in which the load variations occurred. The author met with a similar experience some few years back, with four machines of two different capacities running in parallel, on the occasion of the exhibition in Hamburg. During periods of light load their ampere-meters were very unsteady, swinging continually from zero to maximum and *vice versâ*, an approximately steady balance only being obtained on full load.

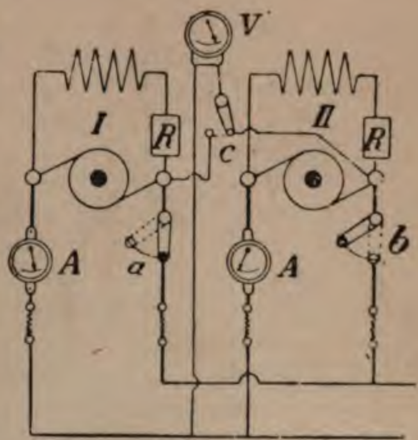

FIG. 56.

Compound-Wound Dynamos. (Figs. 57 and 58.)

We have seen that with series-wound machines the brush

voltage increases with an augmentation of current arising from a lowering of the external resistance. With the shunt-wound machine, on the other hand, an increasing load gives rise to increased armature loss, and consequently results in a diminution of the terminal pressure. By combining the two methods of winding, we are therefore enabled not only to construct a machine which will generate at an absolutely constant terminal pressure, but also, should it be desirable, by so-called "over-compounding," to maintain constant the difference of potential at the farther extremities of the distributing leads.

An example will make clear the peculiarities of the latter method. Let us assume a condition in which the distributing network of conductors is situated at some distance from the

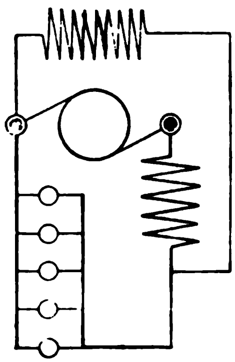

FIG. 57.

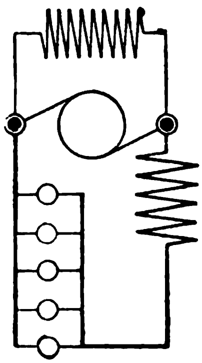

FIG. 58.

generator, the total drop in the leads at maximum load amounting to about 14 per cent. of the dynamo voltage.* It is obvious that under these conditions, even with a constant difference of potential between the brushes, the pressure at the remote ends of the distributing leads will never remain constant, but will vary from 0 to 14 per cent. according to the load. The natural consequence of this will be, on the one hand, a want of uniformity in the illumination over different sections of the network, and, on the other, too high a voltage for the lamps that may remain burning after most of the load has been switched off, whereby their lives will be

* In practice this percentage should never be so high.

appreciably shortened. These disadvantages might, indeed, be overcome by means of suitable mechanical or electrical regulating devices; but this would, to say the least, always involve complications and additional expenditure, whereas in the over-compounding method of winding we have a far simpler remedy for the difficulties.

As an illustration, we will take as our generator the shunt-wound machine mentioned on p. 91, assumed to be provided with a special compound winding (Fig. 58).

Let the pressure between the ends of the line = 110 volts, the number of lamps = 500; and therefore

Strength of the current	= 250 amperes
Resistance of the mains	= 0·05 ohm
" " compound winding	= 0·008 "
" " armature	= 0·016 "
Loss of current in the shunt winding (3 per cent.)	= 7·5 amperes.

The loss of pressure in mains and dynamo is, therefore, by Fig. 58

$$250\,(0{\cdot}05 + 0{\cdot}008) + (250 + 7{\cdot}5)\,0{\cdot}016 = 18{\cdot}6 \text{ volts.}$$

To this must be added the loss of pressure arising from armature reaction, which we estimate at 7 per cent. = 9·4 volts.

Therefore, if 110 volts are to be obtained at the end of the main, the E.M.F. of the machine must be

$$E = 110 + 18{\cdot}6 + 9{\cdot}4 = 138 \text{ volts.}$$

Say that the trial design (Fig. 54) has 600 windings per coil; according to the magnetisation curve it requires $10{\cdot}5 \times 600 = 6{,}300$ ampere turns to produce 138 volts.

If instead of 500 lamps only a few are switched on, then the current falls to zero, and the loss of pressure may be practically considered as nil. The dynamo has, in consequence, to produce no more than 110 volts, and as the compound winding does not produce any effect at no

load, the shunt winding alone must be able to produce 110 volts. The necessary number of ampere-turns is $5 \times 600 = 3{,}000$.

It is clear that the excitation of the shunt is not constant, but increases with the load; this allows of somewhat smaller compounded windings being used. At full load we get at the terminal of the shunt a pressure of

$$138 - 9{\cdot}4 - (250 + 7{\cdot}5)\, 0{\cdot}016 = 124{\cdot}5 \text{ volts.}$$

The current increases, therefore, in the thin windings at the ratio of $\frac{124{\cdot}5}{110} = 1{\cdot}13$, and the acting number of ampere-turns rises to $3{,}000 \,.\, 1{\cdot}13 = 3{,}400$ ampere-turns, so $6{,}300 - 3{,}400 = 2{,}900$ ampere-turns still remain for the compound windings.

We can now proceed to the calculation of the thickness of wire and length of turns.

Length of a shunt winding, $L = 0{\cdot}78$ m.

Length of a compound winding, $L' = 1$ m.

Number of coils, $N'_m = 4$.

Loss of pressure in series winding (1·8 per cent.),

$$\epsilon\, E = 0{\cdot}008 \,.\, 250 = 2 \text{ volts.}$$

Loss of current in shunt winding (3 per cent.),

$$\epsilon\, C = 0{\cdot}03 \,.\, 250 = 7{\cdot}5 \text{ amperes.}$$

Applying equations (62) and (64) we find—

(*a*) Shunt winding—Section of wire

$$s = \frac{(C_m \,.\, N_m)\, N'_m\, L}{E \,.\, 50} = \frac{3{,}000 \,.\, 4 \,.\, 0{\cdot}78}{110 \,.\, 50} = 1{\cdot}7 \text{ sq. mm.}$$

Number of turns per coil

$$N_m = \frac{(C_m\, N_m)}{\epsilon\, C} = \frac{3{,}000}{7{\cdot}5} = 400.$$

(*b*) Compound winding—Section of wire

$$s = \frac{(C_m\ N_m)\ N'_m\ L'}{\epsilon\ .\ E\ .\ 50} = \frac{2{,}900\ .\ 4\ .\ 1}{2\ .\ 50} = 116 \text{ sq. mm.}$$

Number of windings

$$N_m = \frac{(C_m\ N_m)}{C_m} = \frac{2{,}900}{250} = \text{(about) 12 windings.}$$

If it is found afterwards that the compound winding acts too strongly, method Fig. 57 may be used, by which the pressure on the shunt does not increase too much.

If the machine is to give a constant voltage, the calculation is simplified by using above Fig. 57, as in this case the difference of the pressure on the shunt winding remains constant; besides, this has the advantage that method Fig. 58 may be used afterwards all the same in case the compound winding is not sufficiently effective.

A glance at the magnetisation curve is sufficient to show that the working saturation has to be chosen in such a manner that from no load to full load the flux remains nearly proportionate to the excitation. If this rule is not observed, it may easily occur at half load that the potential difference is too large. Just as shunt-wound machines are regulated, so also are compound machines—that is, by the insertion of a variable resistance in series with the shunt winding.

Compound machines are not adapted for charging accumulators, because, in the eventuality of a back current from the battery, the magnets become reversed, causing, maybe, a short-circuit. Nevertheless, necessity may, under certain circumstances, dictate their employment for the above-mentioned purpose, as, for instance, when a compound machine happens to be already installed and it is subsequently desired to supplement the plant with accumulators. In such an event, no care should be spared in arranging the requisite preliminary details, if it is wished to preclude the possibility of breakdown.

At the electric tramway depôt in Zürich, where compound machines are installed, the compound winding is entirely switched out during parallel working with the accumulators, only being employed when the machines are running clear.

Compound machines are indispensable for electric tramway

either by switching extra resistance into the field circuit or diminishing the speed.

B. Comparison between the Three Methods of Winding for Dynamos Designed for the Transmission of Energy.

The Series Machine Considered from a General Point of View.

The electrical phenomena arising during the transmission of energy by means of two series-wound machines may be summarised in the following manner:

Every variation in the load on the secondary machine is attended with a corresponding increase or decrease of the total current flow; hence, as the terminal pressure of the generator is dependent not only on the armature speed but also upon the field-magnet excitation, it follows that the pressure at the terminals of both the generator and the motor will vary within considerable limits, according to the load and resistance of the leads. The variable values relative to the secondary machine are thus: (1) the terminal pressure $E_1 = E - C\ R$; (2) the total induction, ϕ, generated by the magnet windings; hence, a constant speed is only possible so long as the quotient given by $\frac{E}{\phi}$ maintains a constant value, no matter how great the fluctuations in pressure may be.

Hence it becomes obvious that, when constant speed is required, the coupling in parallel of two or more series motors, of which, perhaps, only one is subject to considerable variations of load, with a single series machine acting as generator, is quite impracticable. Each variation in the load upon the one motor will cause a corresponding change in the current generated, consequently also a fall or rise of the terminal pressure of the generator, thus affecting all the motors, not, however, weakening or strengthening their respective magnetic fields in the same proportion, so that the speeds of the several motors must, perforce, considerably differ. This disadvantage is partially avoided by the arrangement shown in Fig. 61. Should, for instance, motor (1) happen to be carrying the heaviest load, the current flowing through armature (1) would distribute itself evenly between

all three magnet windings—assuming, of course, that the latter are of like resistance. It is just at this point, however, that the difficulty arises, since it is practically impossible to adjust the several resistances to be exactly equal. Moreover, it is frequently necessary to drive a number of motors of different powers from the same generator, in which event the above-mentioned condition is, in any case, unattainable. An arrangement such as shown in Fig. 62 is, therefore, to be preferred, providing the motors are not situated too far apart; here the resistances of the magnet coils do not come into account.

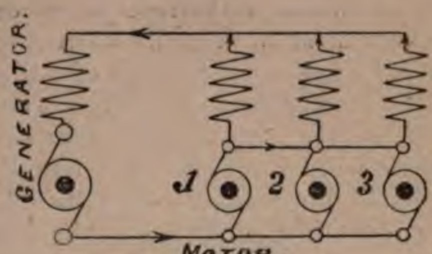

FIG. 61.

The running of series machines in series, in spite of a considerable initial saving in the cost of leads, always has its disadvantages, for certain difficulties are always experienced in switching single motors in or out of circuit. In fact, without special provisions for regulation, those motors which may remain on circuit after the withdrawal of one or more of their companions will be subjected to an acceleration of speed.

Where several generators are employed, this might certainly be remedied by withdrawing a number of generators equivalent to the motors; this, however, as all who have had experience in such installations will know, is not always a simple matter of accomplishment, especially when each generator is separately driven by a turbine. On the latter account preference is given to a system whereby both generators and motors are supplied with automatic regulating apparatus designed to maintain a constant current in the former and constant speed in the

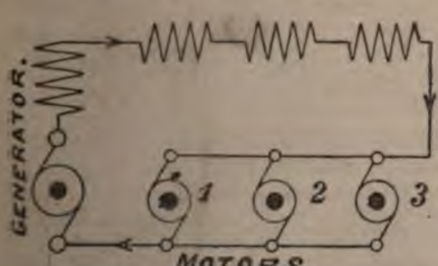

FIG. 62.

latter. Naturally this conduces to no slight complication of the installation.*

In order to keep the initial cost of cables within the lowest possible limits, and at the same time to be able to switch in or withdraw the motors as desired, the so-called three-wire system or a multiple-wire system is often employed.† Fig. 63 represents the plan of a three-wire system.

So long as the two motors are equally loaded, the conditions will be the same as with four machines coupled in series; there will be no flow of current through the middle wire, *b*. Should, however, this load balance between the two motors be disturbed, there will arise a flow of current through *b* equal in value to the difference between the armature currents of the two secondary machines. In event of one motor running light or being entirely withdrawn, *b* would, of course, be called upon to carry the maximum current. The carrying capacity of the middle wire should therefore be equal to that of either of the outer ones, or even greater; for otherwise the terminal tension of the remaining motor would be subject to considerable fluctuations. This arrangement certainly does not conform to the requirements for perfectly constant speed.

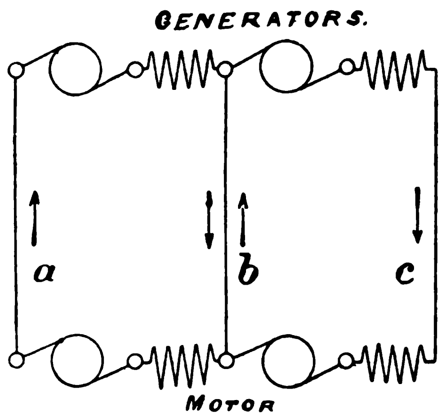

FIG. 63.

* Although a number of power transmission installations (for the most part working at considerable pressures over long distances), established according to this system by the Compagnie de l'Industrie Electrique, Geneva, have been running for some years, thus dispersing all doubt as to the practicability of the method, the author feels that in this case the use of continuous currents has reached its limits, and might with advantage be replaced by alternating currents. However, systems of distribution with series motors may be advantageously used when it is necessary to utilise the energy of a waterfall of variable height; in this case the variations in the frequency of the current produced in alternating machines introduce great difficulties.

† In the Steirmüehl system, laid down by the Oerlikon Company, eight dynamos are coupled up on this system.

of the secondary machines on all loads, but in many cases small fluctuations of speed are of no consequence.

Proceeding to the consideration of power transmission over great distances with the use of two secondary machines, the question arises as to whether or not the three-wire system is preferable to the two arrangements previously mentioned.

On this point it is naturally impossible to draw rigid conclusions, since local conditions always constitute the governing factor. It is a well-known fact that, by giving sufficient attention to details, direct-current machines (especially where ring armatures are employed) may be designed for pressures up to 3,000 volts, and higher. Moreover, it is agreed that a pressure of 1,000 volts is just as dangerous to human life as one of 2,000 volts, while it must be further borne in mind that two primary generators of equal outputs cost considerably more than would a single machine of double the output of either. Nevertheless, a decision in favour of the three-wire system may often be traced to local conditions; sometimes it is adopted for the sake of greater security in working, at others because it is desired to utilise two different sources of water power for the combined transmission scheme.

For certain reasons that may be easily understood, the driving of series motors from a current source at constant pressure is avoided when the motors are liable to great variations of load or momentary periods of light running, as in the event of such an occurrence the exciting current would sink almost to nothing, and the armature would commence to revolve with alarming velocity.

Series Motors for Tramways.

For traction work, where the motors are directly coupled with the axle shafts, so that they can never by any means run light, series machines obtain the preference, since, besides greater efficiency of insulation, this type possesses various advantages appertaining to starting, control of speed, and so forth.*

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* Very small motors of from $\frac{1}{8}$ h.p. to $\frac{1}{16}$ h.p. for driving sewing machines, etc., and intended for running on lighting circuits, can only for technical reasons be wound as series machines. Destruction of the armature insulation at no load is, however, less to fear here, as the frictional resistance is disproportionally great.

As is well known, electric tramways may be worked on two distinct systems: (*a*) by means of accumulators, whereby the driving power is carried on the car itself; (*b*) by means of overhead or underground conductors connected with a central generating source.

It stands to reason that the methods of electrical control must differ correspondingly. When accumulators are employed the matter is, indeed, very simple, the whole battery being divided into equal and independent sections and wires run from the terminals of each to a special controlling apparatus. In starting a car all of these sections are grouped in parallel. As the resultant E.M.F. is very low, the car starts at a small velocity; to accelerate the speed, successive groups are switched over in series as required, until at maximum speed the whole are so disposed.

The methods of control in the second system are entirely different.

From what has previously been said, four methods may be conceived by which a regulation of the speed might be accomplished:

1. By inserting a variable resistance in the motor circuit so as to regulate the terminal pressure in conformity with the speed.

2. While maintaining a constant pressure, the number of ampere-turns comprising the field winding may be varied by means of a controller similar to that mentioned in connection with accumulator working, whereby the saturation of the field is suitably modified.*

3. In practice the above two methods are also employed in conjunction; this is the most satisfactory means of control. Whilst, however, some designers employ a special set of resistances for switching in series with the field circuit, others (notably the well-known American engineer. Mr. Sprague) so proportion the resistance of the magnet coils as to obviate the necessity for a supplementary resistance. But whether an advantage is thereby gained may, perhaps, be doubted, since undue heating of the magnet coils, and consequent detriment to their insulation, must result.

4. Should the car be equipped with two motors, both may.

* The first application of this method was made by Marcel Deprez as early as 1883 (*La Lumière Electrique*, April 11, 1885).

on starting, be put in series through a resistance. The initial speed is in this manner very much reduced. In order to increase the velocity, successive resistance coils are switched out, and ultimately the two motors are coupled in parallel.

The theory of tramway motors and their control constitutes a subject of such importance to the electrical engineer of the present day, that we will here consider the matter a little more fully.

The velocity of a motor is given by the formula—

$$n = \frac{E \cdot 60 \cdot 10^8}{N \cdot \phi} \cdot \frac{p_1}{p}.$$

It will, however, almost invariably be found more convenient in practical calculations to use the car velocity, v, in metres per minute, rather than the revolutions, n.

Let D represent the diameter of the car wheels in metres, and a the ratio of the gearing, then

$$v = \frac{\pi D n}{a};$$

$$v = \frac{E \cdot 60 \cdot 10^8 \cdot p_1}{N \cdot \phi \cdot p} \cdot \frac{D \pi}{a}.$$

In that which follows, only series motors will be dealt with, the peculiar type of their characteristics eminently adapting them for traction work.

The condition common to the great majority of lines of simultaneously running numerous cars conduces to the maintenance of a constant E.M.F. in the generating station, so that the pressure between the motor terminals need only differ by the amount representing the drop of E.M.F. in the conductors.

Let us designate by P the weight in tonnes* to be propelled by the motor—*i.e.*, weight of the car plus weight of load plus weight of the electrical equipment;

v, as above, the car velocity in metres per minute;

α, the coefficient of traction = 10 to 12 for tramways, and 4 to 6 on railways;

β, the per 1,000 gradient.

* A *tonne* = 10^6 grm., and is equal to an English ton to within about 1 per cent. (1 ton = $1{\cdot}017 \times 10^6$ grm.).

The effective propelling force demanded from the motor will then be

$$\text{H.P.} = \frac{v\,P\,(\alpha + \beta)}{75 \cdot 60} \quad . \quad . \quad . \quad . \quad . \quad . \quad *(65)$$

or with a commercial efficiency ζ we may ascertain the current absorbed.

$$C = \frac{9{\cdot}81\ v\ P\ (\alpha + \beta)}{E\ \zeta\ 60} = \text{const.}\ .\ v\ (\alpha + \beta). \quad . \quad (66)$$

where P, E, and ζ are taken to be constant.

The latter formula serves to ascertain the current and the velocity of the car for any gradient. To this end we fit the motor with a brake, and then note the revolutions made by the armature and the corresponding current, the E.M.F. remaining constant. By adjusting the bearing pressure of the brake to represent the different additional resistances to be overcome in ascending various inclines, a complete set of tests may be made and the results graphically plotted out: here, instead of the revolutions, it is customary to set down the equivalent velocity of the car, or else to give both values. Fig. 64 represents such a characteristic.

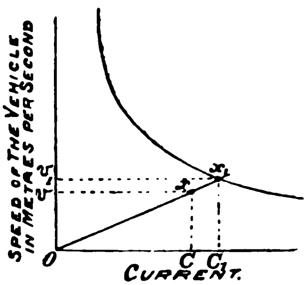


FIG. 64.

Even before the motor is constructed this curve may easily be calculated out and plotted; regard must be given to the fact that the actual number of revolutions does not attain to its theoretical value for a given current.

* A method precisely similar to that used in this problem may be employed when the data given are in the English system. The characteristic is then drawn with *miles per hour* as ordinates, instead of *metres per minute*, as in Fig 65. The formulæ used take the following forms:

$$v \text{ (in miles per hour)} = \frac{\pi\,D\,n}{5{,}280\,a} = \frac{E \times 60 \times 10^8 \times p_1}{N\,.\,\phi\,.\,p} \cdot \frac{0{\cdot}0114\,D\,\pi}{5\,280\,a};$$

$$\text{H.P.} = \frac{1{,}609 \times 1{\cdot}016\,v\,P\,(\alpha + \beta)}{75{\cdot}9 \times 60 \times 60} = 0{\cdot}006\,v\,P\,(\alpha + \beta). \quad . \quad . \quad (65)$$

$$C = \frac{4{\cdot}46\,v\,P\,(\alpha + \beta)}{E\,\zeta} = c'\,v\,(\alpha + \beta)\,. \quad . \quad . \quad . \quad . \quad . \quad (66)$$

In these formulæ P may be taken either in *tonnes* or *tons* (see note, p. 107).

We thus have two unknown quantities, C and v, which must fulfil the conditions: (1) that they be included in the characteristic; and (2) that they satisfy equation (66).

The problem involved is a very simple one.* We calculate C for any v, and then draw from x, the point found, a straight line, Ox, through the origin of co-ordinates Now produce the line Ox until it cuts the characteristic in x_1. The co-ordinate corresponding to the latter point gives us the actual velocity of the car v_1, corresponding to a current consumption C_1.

In making such calculations one naturally sets down for v a value approximating to the minimum velocity, except when it is desired to ascertain the speed which will be attained by the car on downward gradients, in which case it is preferable, for the sake of greater exactitude, to use a greater value for v.

Example 1.—Let it be required to calculate, on the basis of certain given conditions, the ratio between current consumed and the resultant velocity in ascending various gradients with a car accommodating 32 passengers. Let the maximum gradient amount to 50 per 1,000. Further, we will take the tractive coefficient at 10 kgrm. per tonne. The total weight of the car may now, if we make a preliminary estimate of the weight of the electrical equipment, be tabulated as follows:

Weight of car itself	2·80	tonnes.
,, electrical equipment	1·40	,,
,, passengers	2·24	,,
Total weight	6·44	,,

The maximum tractive power required consequently = $(10 + 50)\ 6{\cdot}44 = 386$ kgrm.

It now remains to decide how far an electrical equipment, designed to furnish the requisite horse-power, conforms to the above estimated weight, and eventually the calculation must be repeated on the basis of the corrected weight. However, it will suit our purpose to assume here that the initial calculation holds good. Let, moreover, Fig. 65

* See an article by the author upon the "Control of Tramway Motors" (*Zeitschrift fur Elektrotechnik*, Vienna, February 1 and 15, 1893); further, the "Solution of Graphical Methods of Practical Questions Concerning Continuous-Current Dynamos" (*Elektrotechnische Zeitschrift*, July 19, 1894).

represent the characteristic of the selected motor, which is designed for a mean working difference of potential between its terminals of 500 volts and an efficiency ζ at maximum load = 0·82, whence, according to equation (66)—

$$C = \frac{9{\cdot}81 \,.\, v\, P\,(\alpha + \beta)}{E\,\zeta} = \frac{9{\cdot}81 \,.\, v \,.\, 6{\cdot}44\,(\alpha + \beta)}{500 \times 0{\cdot}82 \times 0{\cdot}60}$$
$$= 0{\cdot}00256\, v\,(\alpha + \beta).$$

Further, assuming that $v = 195$ m. per minute, we obtain the convenient formula

$$C = 0{\cdot}5\,(\alpha + \beta),$$

which is, however, based on the assumption of a maximum efficiency, C being, as a consequence, given somewhat smaller

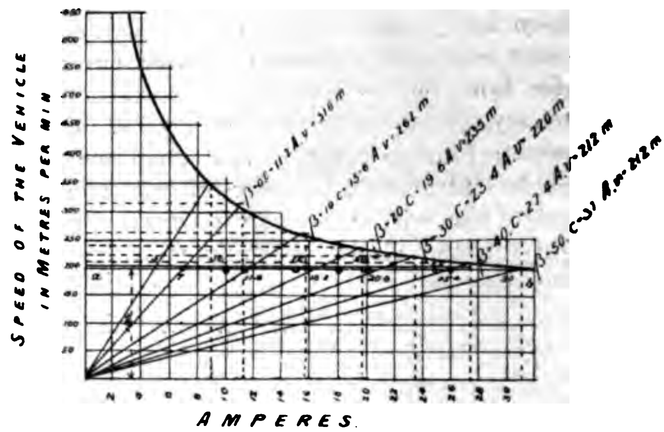


FIG. 65.

and v therefore greater than is found in actual practice. We shall see further on to what correction the result given by this formula must be subjected in order to bring it into conformity with the requirements of exact calculations. For simplicity's sake, let us for the moment assume that ζ maintains a constant value, and the car velocity $v = 195$ m. per minute. Hence, when

$\beta =$ 0 per 1,000, C = 5 amperes.
$\beta =$ 10 ,, C = 10 ,,
$\beta =$ 20 ,, C = 15 ,,

$\beta = 30$ per 1,000, C = 20 amperes.
$\beta = 40$,, C = 25 ,,
$\beta = 50$,, C = 30 ,,

That is to say, every additional 10 per cent. rise entails 5 amperes increase of current over and above that supplied on the level.

We now draw at a vertical distance, 195 (see Fig. 65), the straight line $a\ b$ parallel to the horizontal axis, and mark off with the compasses the above current values. By connecting these points with the origin, and extending the several lines towards the curve, we obtain at the points in which the characteristic is so cut the values required to a first approximation.

This method suffices, as a rule, for preliminary calculations, the more so if instead of the maximum a mean value be set down for ζ.

More exact results may be obtained in the following manner:

We infer from the foregoing that the maximum current—that is to say, the current corresponding to an efficiency of 0·82—amounts to 31 amperes. It follows that on the level there will be still about 9 amperes, or, in other words, 30 per cent. of the maximum current. Assuming the efficiency of the motor under these conditions to be $58\frac{1}{2}$ per cent. (a figure which we have intentionally placed low in order the better to emphasise our illustration; it is in reality considerably greater), then for $\beta = 0$

$$C = 5 \cdot \frac{82}{58 \cdot 5} = 7 \text{ amperes,}$$

or 2 amperes more than was previously estimated. When $\beta = 50$ the difference is practically negligible.

Thus, in order to determine the exact supplementary current which will be requisite to maintain a velocity of 195 m. per minute over any incline, we must, starting from the point $\beta = 50$, correct the original figures as follows:

$\beta = 50$	per 1,000,	C = 30	amperes.
$\beta = 40$	,,	C = 25 + 0·4 = 25·4	,,
$\beta = 30$	,,	C = 20 + 0·8 = 20·8	,,
$\beta = 20$	,,	C = 15 + 1·2 = 16·2	,,
$\beta = 10$	,,	C = 10 + 1·6 = 11·6	,,
$\beta = 0$	,,	C = 5 + 2 = 7	,,

For the rest the method of calculation previously given holds good.

In considering gradients with a fall of less than 10 per cent. β must be subtracted from α.

This single example may perhaps suffice to show that *tramway motors should, above all, be designed for strong saturations, so as to avoid a disproportionately high velocity on the level.*

We will now return to the consideration of the several methods of speed control in vogue.

(a) Control by Means of Switching Resistances in the Motor Circuit.

If we suppose that a motor in driving a car over any gradient, without supplementary resistance in circuit, runs at a certain definite speed, v, whereby the current consumed = C amperes, and the combined resistance of magnet and armature amounts to r ohms, then

$$v = c \cdot \frac{\mathrm{E} - \mathrm{C}\,r}{\phi} = \frac{\mathrm{E} - \mathrm{C}\,r}{f(\mathrm{C})}.$$

Further, the energy utilised in watts is given by

$$\mathrm{W} = \mathrm{C}\,(\mathrm{E} - \mathrm{C}\,r) - w,$$

where w represents the hysteresis and friction losses.

In order to reduce the speed of the motor to v, a certain resistance, R, must be switched into its circuit. Without investigating the correctness of our supposition we will now assume that a current consumption C_1 results from the modified speed, v_1, whence it follows that

$$v_1 = \frac{\mathrm{E} - \mathrm{C}_1\,(r + \mathrm{R})}{f(\mathrm{C}_1)},$$

and the energy utilised under the altered conditions

$$\mathrm{W}_1 = \mathrm{C}_1\,[\mathrm{E} - \mathrm{C}_1\,(r + \mathrm{R})] - w_1.$$

It is evident that we require the following relation to hold:

$$\mathrm{W} : \mathrm{W}_1 = v : v_1;$$

or, substituting the individual values—

$$\frac{\mathrm{C}\,(\mathrm{E} - \mathrm{C}\,r) - w}{\mathrm{C}_1\,[\mathrm{E} - \mathrm{C}_1\,(r + \mathrm{R})] - w_1} = \frac{\dfrac{\mathrm{E} - \mathrm{C}\,r}{f(\mathrm{C})}}{\dfrac{\mathrm{E} - \mathrm{C}_1\,(r + \mathrm{R})}{f(\mathrm{C}_1)}};$$

$$C f(C) - f(C) \frac{w}{E - C r} = C_1 f(C_1) - f(C_1) \frac{w_1}{E - C_1 (r + R)};$$

we have $$w : w_1 = v : v_1.$$

Substituting the respective values of v and v_1, it follows that $$C \,.\, f(C) = C_1 f(C_1).$$

From this equation it becomes apparent that C must equal C_1, since if, for instance, $C_1 >$ or $< C$, it would follow that $f(C_1) >$ or $< f(C)$, so that the above equation could not be satisfied.

A similar result may be obtained much more quickly by regarding the tractive power of the motor as the product of the current into the strength of the field—that is to say, $C f(C) = C_1 f(C_1)$. (Compare p. 14.)

It is thus certainly possible by switching resistance into its circuit to vary the speed of the motor to any degree, the current meanwhile remaining invariable.

If the tractive coefficient equals 10, a gradient of at least 10 per 1,000 will be essential in order that the car should start without assistance from the motor. Assistance from the motor will therefore be required in descending anything under this gradient. The electrical resistance necessary to be switched into the motor circuit on such a slope would be inconveniently great on account of the small current taken. Hence one has to remain contented in providing a resistance capable of keeping the speed on the level or slight declines (up to 5 per 1,000) within the maximum limit, switching out the motor altogether should the speed in descending more abrupt gradients become too high.

FIG. 66.

Referring to the previous example (Fig. 66), we find that the speed corresponding to a fall of 5 per 1,000 amounts to about 380 m. per minute, whilst the current consumption amounts to 7·6 amperes. Supposing, now, that the maximum speed is not to exceed 250 m. per minute, it will be necessary to reduce the pressure to

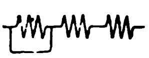
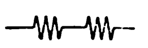
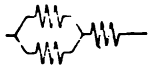
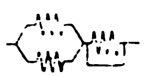
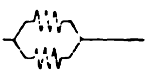
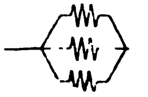
$$500 \cdot \frac{250}{380} = 330 \text{ volts.}$$

Consequently the resistance required

$$= \frac{500 - 330}{7{\cdot}6} = 22{\cdot}4\ \omega.$$

(b) Control by Varying the Disposition of the Field Windings (Sprague System).

In the Sprague system each of the two magnet coils is divided into three sections. Each of these sections, together comprising the winding of one magnet limb, is, moreover, connected in series with the corresponding section belonging to the opposite limb. By means of a special form of controlling switch, consisting of a drum capable of being rotated within a counterpart cylinder fitted with the necessary engaging contacts, connections, etc., seven modifications (as shown diagrammatically in the following table) of the connections between the several coils may be made:

Position.	Method of Connection.	Plan. a b c	Number of Ampere-Turns.	Resistance of a Magnet Winding
1	Coils *a b c* in series.		$3\,C\,N_m$	$3\,r$
2	Coils *b* and *c* in series, *a* short-circuited.		$2\,C\,N_m$	$2\,r$
3	Coils *b* and *c* in series, *a* cut out.		$2\,C\,N_m$	$2\,r$
4	Coils *a* and *b* parallel, and in series with *c*.		$2\,C\,N_m$	$1{\cdot}5\,r$
5	Coils *a* and *b* in parallel, *c* short-circuited.		$C\,N_m$	$0{\cdot}5\,r$
6	Coils *a* and *b* in parallel, *c* cut out.		$C\,N_m$	$0{\cdot}5\,r$
7	Coils *a b c* in parallel.		$C\,N_m$	$0{\cdot}33\,r$

The above resistances are given on the assumption that the several coils possess equivalent resistances; in the original arrangement adopted by Sprague this was not exactly the case.

A superficial glance at the above diagrams makes it evident that the respective arrangements 3 and 6 in no way differ from those denoted by 2 and 5, producing identical effects relative to the modifications of the field and of the resistance. The number of effective modifications which produce different effects is thus reduced to five. At the same time the arrangements 3 and 6 are indispensable, since otherwise short-circuits would be produced when changing over to positions 4 and 7.

Compared with the method of regulation by means of a supplementary resistance, this method possesses the advantage of greater economy, against which, however, must be set down the inconvenience arising from the necessity of so many connecting wires; further, the winding space at our disposal is somewhat inefficiently utilised in consequence of the increased insulation necessitated.

As is self-evident, the employment of a special starting resistance is also not indispensable with this method.

However, precisely similar results may be obtained in a simpler manner by adopting the following arrangement:

(c) Control by Means of Switching Resistances in Parallel with the Magnets.

The peculiarity of this method consists in the employment of magnet windings arranged to carry a smaller current than the armature, and consequently comprising a correspondingly greater number of turns. As soon as the current in the magnet circuit exceeds the value for which the windings were designed, relief is afforded it by switching successive resistances in parallel.

Curve 1 (Fig. 66) represents the characteristic of an ordinarily-wound motor; further, let v_2 be the maximum velocity prescribed by the police regulation, whilst the gradient is denoted by β_2. Should the gradient be greater than β_2, we must reduce speed by switching resistance into the circuit; this produces a drop of voltage. If, as an alternative, we provide the magnet with a winding containing

double the number of turns, we obtain characteristic II., the abscissæ of which are only half as great as those of Curve 1. The points where the curve is cut by the radial lines, o β_1, o β_2, etc., lie relatively much deeper, so that even assuming a gradient

$$\beta_1 = \tfrac{1}{2}(\beta_2 - a),$$

the maximum permissible velocity will not be exceeded.

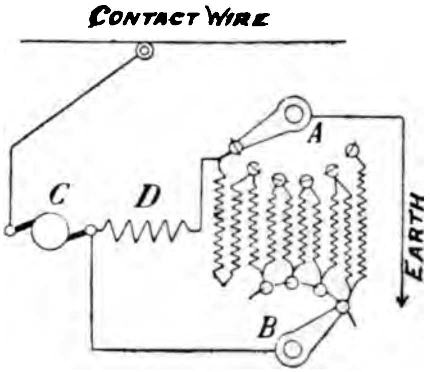


FIG. 67.

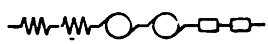
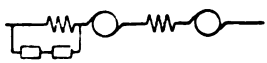
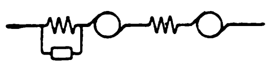
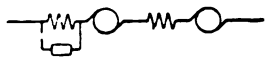
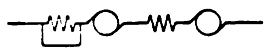
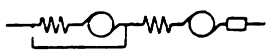
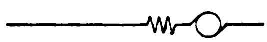
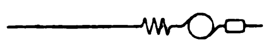
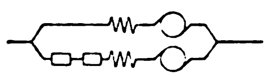
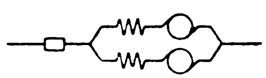
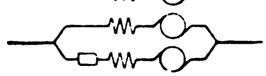
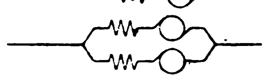
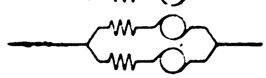
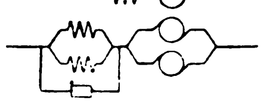
The great advantage of this system consists in the simplicity of the regulating apparatus, as the same resistance which serves for starting may subsequently be utilised for paralleling with the field winding (Fig. 67). The method was employed by the author as early as 1891 on the electric tramway at Marseilles, and has since been exclusively adopted in connection with the recent tramway installations put down by the Oerlikon Engineering Company.

(d) Series-Parallel System.

For cars equipped with two motors apiece, various modifications of the so-called series multiple system are at present in vogue. The peculiarity of this system consists in the motors being arranged for either series or parallel running, according to requirement, being the change over effected by means of one or other of the controlling methods about to be described. The two best known and most extensively adopted types of regulating apparatus for accomplishing the desired end are indisputably those emanating from the Thomson-Houston or General Electric Companies and the Westinghouse Manufacturing Company. Without entering into constructional details, it will suffice to take a brief survey of the methods by which the current strength and resultant velocity over any gradient may be ascertained. The different modifications of the connections provided for in the systems under consideration are given diagrammatically in the following table.

The different positions may be easily analysed by taking the characteristic curve of a single motor as basis for comparison, and constructing therefrom the curves corresponding to the remaining dispositions, finally marking off the points in which they cut the straight line computed from equation (66).

Although the several dispositions have already, in part, been separately dealt with, we shall, for the sake of obtaining a clearer survey, now set them together:

Position.	Method of Control, Westinghouse Company.	Method of Control, General Electric Company.
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

1. Resistance in the armature circuit (positions 1, 2, and 3) and armatures in series (Fig. 68).

Curve I. Characteristic for one machine.

Curve II. Characteristic for the two motors, coupled in series, is found by dividing the ordinates of the first by 2.

R = the supplementary resistance.

$$R = \frac{E}{C} \cdot \frac{a}{b} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (67)$$

$$a = \frac{R\,C\,b}{E}.$$

2. Arrangements 4 and 5, Westinghouse (Fig. 69).

I. Curve for a single motor.

II. and III. Curves relating to the two machines connected in series. We have:

$$E \cdot \frac{a}{b} \cdot C_2 + E\,\frac{b-a}{b} \cdot C_1 = c\,v\,(\alpha + \beta).$$

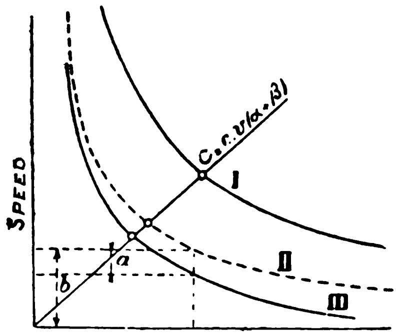


FIG. 68.

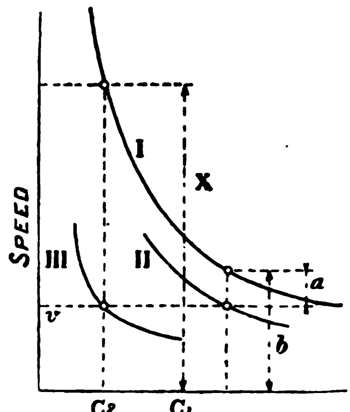


FIG. 69.

Further, $\frac{a}{b}$ must $= \frac{b-a}{X}$; whence

$$X = \frac{b\,(b-a)}{a}.$$

This formula serves to determine C_2 and C_1. To determine R we have:

$$(C_1 - C_2)\,R = \frac{E\,a}{b} \quad . \quad . \quad . \quad . \quad . \quad . \quad (68)$$

The most expeditious means of attaining the desired end is to plot out the respective curves for a single machine and for two motors in series, and then interpolate two intermediate

curves, from which a and b may be obtained, and X and C determined, as shown above. Only the value of R now remains to be ascertained. This is constant for the arrangements 4 and 5; the interpolated curves must be modified accordingly.

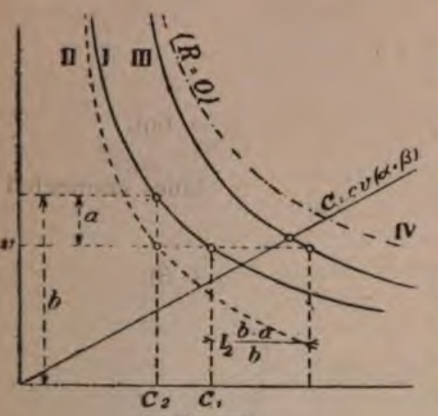


FIG. 70.

Once more employing equation (66), the point of intersection of Curve II. (motor without supplementary resistance) with the radial line will in this instance give us the required velocity and corresponding current consumption.

3. Arrangements 8 and 9, Westinghouse (Fig. 70).

I. Curve for a single motor.

II. Curve for a single motor with resistance in circuit.

III. Curve for the two motors in parallel, with resistance in circuit.

IV. Curve for the two motors in parallel, without resistance in circuit.

$$R = \frac{E}{C_2} \cdot \frac{a}{b} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (69)$$

From this equation we construct Curve II., assuming a definite resistance, R, the original estimation of which must be modified according to circumstances. Curve III. is obtained by adding together C_1 and C_2.

When all the curves have been plotted out and combined in this manner (Fig. 71), we obtain an exact representation of the method of working on any possible gradient. The magnitude of the changes of velocity corresponding to different gradients and methods of coupling may also be readily deduced, as well as those changes which will produce perceptible jerks, etc.

When two motors per car are to be employed, it is of prime importance to always pair machines which possess exactly similar magnetic properties. This precaution is all the more

essential when the brushes are connected together between the commutators and the field-magnet windings. Let us consider, for instance, the effects of working with two 15-h.p. motors (E = 500, C = 26 amperes) whereof the one retains 3 per cent. of its magnetism and the other 6 per cent. when at rest. This difference might arise, quite apart from the use of different materials, through unlike boring of the respective pole-pieces. Further, let the drop in voltage due to the resistance of the first armature be 3 per cent., which corresponds to 0·58 ohm, then in descending a gradient a pressure of (0·06 – 0·03) × 500 = 15 volts will be generated, which in turn will give origin to a current of $\frac{15}{0{\cdot}58 \times 2}$ = 13 amperes = 50 per cent. of the normal current. For the rest, experience has shown that under certain unfavourable conditions this current may even exceed the normal current taken by the machine. But since this current is not furnished by the supply leads, it is naturally of no consequence regarded in the light of a wasteful consumption of energy; we have, however, to consider that such a condition of things renders the motors liable to considerably greater heating, since they are still being heated when descending gradients, which would otherwise supply intervals for cooling.

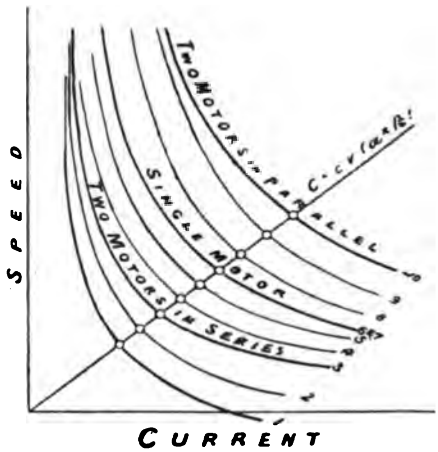


FIG. 71.

In designing power stations for traction purposes, besides the estimated mean current consumption, the probable maximum current must be taken into account. Unfortunately, there exists no formula which enables us to calculate the requisite starting current with absolute exactitude, but that given below, due, as far as we are aware, to Messrs. Oscar

T. Crosby and Louis Bell, leads to moderately correct results ("Electric Railway in Theory and Practice"):

$$\text{Starting current } C' = C \frac{3\alpha + \beta}{\alpha + \beta} \quad . \quad . \quad . \quad . \quad (70)$$

where C = the current necessary for running on the particular gradient for which the starting current is to be determined. On the level $\beta = 0$, so that the starting current is three times as great as that sufficient to keep the car in motion when once under way. The results given by this formula also agree very well with actual observations made some years since over the Zürich-Hirslanden line at the instance of the Oerlikon Engineering Company.

Shunt-Wound Machines.

We will now consider the shunt-wound machine in its capacity as motor; we have already seen that, running as a generator, a machine of this type—apart from a small loss—enables a practically constant pressure to be maintained, whatever may be the variations in the current demand. Driven, on the other hand, as motor, a shunt-wound machine will run with tolerably constant speed on any load within wide limits—the working of several machines simultaneously on the same main making no difference. Another advantage possessed by motors of this type consists in their magnets being always—even during light running—sufficiently saturated to preclude burning out of the armature.

In starting such a motor it is essential to switch a supplementary—though proportionally very small—resistance into the armature circuit, since were a standing shunt-wound motor thrown in circuit without this addition the primary machine would be short-circuited and its poles reversed. Overloading of the motor may also conduce to a similar result. The employment of a starting resistance is none the less necessary even if the primary machine generates at a constant terminal pressure, since, as regards the motor, the resistance and induction of the armature circuit are so small in comparison with the corresponding properties of the magnet winding, that in attempting to start without such provision no appreciable flow of current through the latter would result; consequently

the torque requisite to set the armature in motion would not be produced.

An artifice sometimes employed so as to avoid the employment of extra resistance in starting shunt-wound motors consists in lifting one of the brushes for a short time, thus allowing the magnets to become thoroughly saturated, whereupon, the armature having been set in the quickest possible rotation by hand, the brush is again depressed. Such makeshifts are, however, to be condemned, since they are very liable to occasion injury, not only to the windings, but also to the commutator and brushes.

Should it be desired to vary the speed of a shunt-wound motor, this may be accomplished by employing one of the types of resistance already mentioned, the proportions being naturally selected to correspond with the particular requirements of the case; or, as an alternative, we may employ an arrangement for grouping sections of the magnet winding in series or parallel. With the latter method, however, the different arrangements as to grouping effect results which are just the reverse of those obtaining with the machine running as a generator.

Let, for instance, the winding be divided into six sections, then denoting by

E, the pressure between the brushes;
r, the resistance of a single section; and
N, the number of turns per section, we shall have:

With all the coils in series:

$$C_m \, N_m = \frac{E}{6\,r} \cdot 6\, N_m = \frac{E}{r} \, N_m;$$

With two groups in parallel, each consisting of three coils in series:

$$C_m \, N_m = \frac{E}{\frac{3}{2} \cdot r} \cdot 3\, N_m = 2 \, \frac{E}{r} \cdot N_m;$$

With three groups of two coils each:

$$C_m \, N_m = \frac{E}{\frac{2}{3} \cdot r} \cdot 2\, N_m = 3 \, \frac{E}{r} \cdot N_m;$$

With all the coils in parallel:

$$C_m \, N_m = \frac{E}{\frac{1}{6} \cdot r} \cdot N_m = 6 \, \frac{E}{r} \cdot N_m.$$

The maximum speed, therefore, corresponds to the first, and the minimum speed to the last method of grouping. It is beyond all doubt that the employment of shunt-wound machines, both as generators and motors, offers, in many cases, decided advantages; this is especially the case if the motors are to be connected to lighting mains and a constant speed at all loads is required, as for instance, in driving machine tools, etc. Neither do conditions which entail a considerable drop of voltage in the mains—thus rendering a considerable variation of the terminal voltage possible—preclude employment of shunt-wound motors, for the type is not highly sensitive to fluctuations of pressure. As a matter of fact, a shunt-wound motor might be rendered completely insensitive, between certain limits which will be prescribed by the degree of sparking admissible, by so designing the magnets of the secondary machine that when running light (in other words, when the loss of pressure is an almost negligible quantity, and the primary and secondary machines, therefore, possess equal terminal pressures) they are still saturated to a degree sufficient for proportionality between exciting current and resultant induction to exist. The proof of this may be readily obtained: $v = c \frac{E}{\phi}$, or since $\phi = c_1 \frac{E}{R}$, it follows that $v = c_2 R$.

Experience has shown that the minimum weight of a dynamo is only attainable by working in the neighbourhood of the "knee" of the magnetisation curve, that is to say, in that part of the curve where proportionality between induction and excitation does not exist. An easy means of providing for this case consists in employing a compound-wound machine as generator and a shunt-wound one as motor, obtaining a constant pressure between the terminals of the secondary machine by over-compounding the windings of the generator.

A further advantage accruing to the use of compound-wound dynamos as generators for transmission work, in preference to simple shunt-wound machines, is that they are not liable to demagnetisation through overloading of the motor. For this reason generators for traction work are, with few exceptions, compounded.

Arrangements for Starting Shunt-Wound Machines.

Shunt-wound machines require a particularly good insulation for the field-magnet circuit, to prevent damage being incurred in putting them out of circuit.

This inconvenience can be obviated, to a certain extent, by the use of an arrangement which was employed by the author in March, 1892, with a portable shunt-wound motor constructed by the Oerlikon Company (Design No. 2,945). Use is made of an ordinary regulating rheostat similar to that used with a series-wound machine, but in this case connected to the terminals of the machine in the manner shown in Fig. 72. In virtue of this arrangement, M always forms a closed circuit with the armature, A, and the starting resistance, R. Thus the motor may be put out of circuit without the production of sparks. As may be seen, in the last position (7) all the regulating resistance is included in the field-magnet circuit; nevertheless, the speed is not appreciably affected, as may be shown by the following reasoning: Suppose that the starting resistance, R, is selected so that the current on starting should not exceed half of its normal value, and that the magnetising current should be equal to 3·5 per cent. of the principal current, we shall then have, neglecting the resistance of the armature,

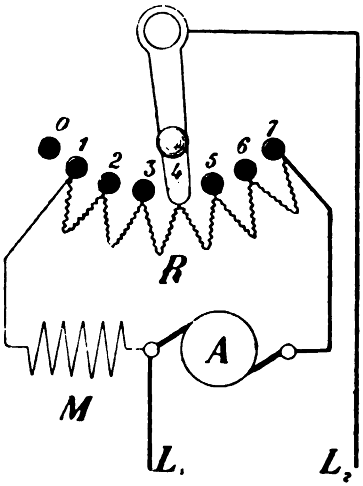


FIG. 72.

(*a*) $$R = \frac{E}{0·51};$$

(*b*) $$\frac{E}{r} = C_m = 0·035\ C, \text{ whence } r = \frac{E}{0·035\ C};$$

(*c*) $$C'_m = \frac{E}{R + r} = \frac{0·035 + 0·5\ C}{0·35 + 0·5} = 0·0327\ C.$$

Consequently the exciting current is only enfeebled to the extent of about 7 per cent., the speed being thus increased by about 2 per cent.

Similar arrangements have been proposed by Menges (*Elektrotechnische Zeitschrift*, No. 48, 1897, and *Eclairage electrique*, April 16, 1898; "Machines Dyn. Elec.," by M. C. F. Guilbert); and by Cutler, of Chicago (see English patent 13,523, June, 1897). In Menges's arrangement (Fig. 73) two contact makers are used. The resistance of the field magnets remains the same under all conditions. In order to render the motor reversible, Mr. Menges proposes to supply a commutator, U, between the terminals, *a* and *b*, so arranged that the circuit can never be broken whatever may be the position of the commutator.

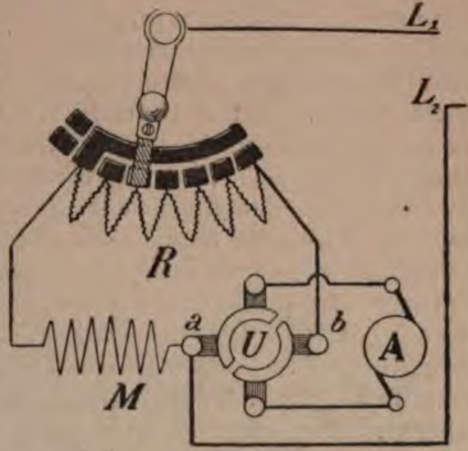


FIG. 73.

C. Direction of Rotation of Motors and Generators.

Generators.

As far back as pp. 6 and 14 a method was explained by which we can determine the direction of the current in a conductor moving at right angles to the lines of force of a magnetic field. We shall now show that the field winding of a machine must be connected with the armature in a certain definite manner in order to obtain a current with a given direction of rotation.

When running a machine for the first time it is necessary, as a rule, to separately excite its field for a brief period, since the magnet limbs of absolutely new machines seldom possess distinct poles. However, after this has once been performed the iron constituting the magnet core retains a certain permanent magnetisation, which, although certainly very

weak, nevertheless suffices to generate a small induction current in the armature when starting.

Now, in starting the machine, provided that the magnet-winding connections have been correctly made, this current, initially very weak, will strengthen the residual magnetism. Thereby the induction current is also increased; the resultant stronger excitation, in turn, generates a larger number of lines, and so on, until a certain condition of balance corresponding to a definite degree of saturation is attained.

Supposing, on the contrary, that the connections have been incorrectly made, the small current initially induced in the armature will tend to reverse the weak magnetisation already existing in the field magnets. A permanent current will therefore only be possible after the magnets have been completely demagnetised. As soon, however, as the field entirely disappears, the armature current likewise sinks to zero—that is to say, the machine simply ceases to generate a current. Should, in such an eventuality, the existing conditions not admit of the direction of rotation being altered, there remains no remedy but to cross the field-magnet connections—or, what under certain circumstances is still better, to interchange the magnets themselves. The latter plan is not, however, feasible with all types of machines.

We may here call attention to some further peculiarities which are liable to cause trouble when insufficient care has been taken.

Machines with exactly similar windings and the same direction of rotation may generate oppositely directed currents, due to a difference in their initial magnetisation.

We will take a shunt-wound machine to illustrate the truth of this statement, although the law applies equally to other types of machines. Let us assume the machine (Fig. 74*a*) to revolve in the sense of the hands of a watch, and that the N pole-piece is above the armature, the S pole-piece being below. In this case the positive brush will be to the left of the diagram, and if the connections shown in Fig. 74*a* are made, the machine will excite itself.

Suppose, on the other hand, that the initial excitation of the magnets had been in the reverse position (Fig. 74*b*), so as to have generated the upper and lower poles of negative

and positive sign respectively. Then the current subsequently generated in the armature will naturally be of reverse direction as compared with the previous example; that is to say, the positive brush will be to the right of the diagram.

If we trace the direction of the current flowing round the shunt coils (Fig. 74*b*), it becomes obvious that it tends to maintain the upper and lower poles respectively of negative and positive sign, so enabling the machine to continue working. With regard to installations confined exclusively to incandescent lighting, it is a matter of indifference in which direction the current flows; whereas when the machines are

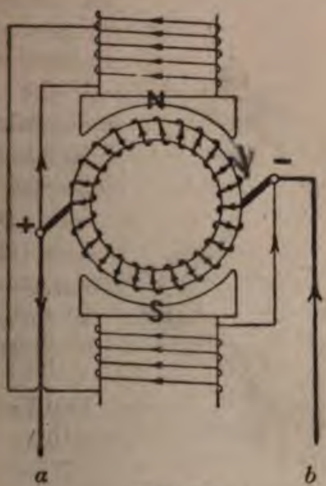


FIG. 74*a*.

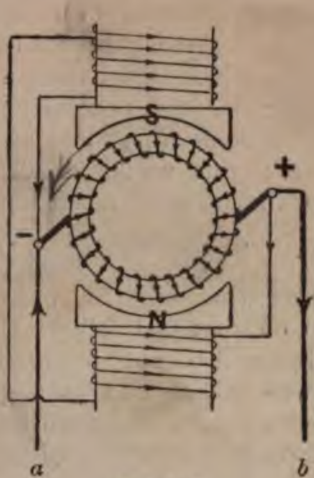


FIG. 74*b*.

destined for arc lighting, electro-metallurgy, or the charging of accumulators, etc., the respective poles must first of all be determined. The same necessity arises when machines are to be run in parallel.

Advantage may be taken of this opportunity to remark that the lives of incandescent lamps may be appreciably prolonged by occasionally changing the poles of the machines supplying them with energy; little or no use is, however, made of this in practice.

To determine the respective poles, use may be made of the well-known special appliances—*i.e.*, Berghausen's pole-finder, pole-finding paper, and such like. Should an arc

lamp be opportunely to hand, we might connect the same in circuit with the machine, and after a time switch off the current. That carbon which, after this has been done, continues to glow the longer will be the positive one. When shunt or compound wound dynamos are to be run in parallel, the poles of like sign may be discovered by means of two incandescent lamps arranged in series. To this end we join, trial-wise, a terminal of the one machine with either of those belonging to the other. The two remaining terminals are then connected through the lamps. If the right connections have been hit upon, there will naturally be no flow of current through the lamps.

During transport over long distances, machines are very liable to lose their residual magnetism owing to the severe shakings which they undergo. A few Daniell elements suffice, however, for the necessary remagnetisation. Before leaving the test-room, every machine should have its terminals plainly marked; this would entail little extra trouble, but would spare the installer much annoyance.

Motors.

From what has just been said, as likewise from the rule given on p. 14, it follows that the sense in which a motor revolves will be opposite to the sense of rotation of the same machine when used as a generator, if, in the motor, the currents in the armature and field magnets are either both similarly or both oppositely directed to those in the generator. The directions of rotation of similarly-wound series machines are thus invariably opposite, accordingly as they are run as motors or generators. On the other hand, shunt-wound motors possess the same direction of rotation as the primary machine. From this we are able to deduce some further conclusions:

1. Series machines, when driven as generators in the same direction of rotation as that in which they would run as motors, give no current. A current is initially generated in the armature, but being of a contrary direction to that required it ends in demagnetising the poles. Thus, in power transmission plants with series machines where the motor, for instance, has to work conjointly with a steam-engine on the same shafting, the primary machine may

without hesitation be shut down even on a closed circuit whilst the motor is still coupled to the shafting.

2. On the contrary, a shunt-wound machine, when driven mechanically in the same direction as that in which it has been running as a motor, generates an oppositely directed current. Should it therefore be desired to employ shunt-wound instead of series-wound machines for such auxiliary transmission plants as that mentioned above, provision must be made whereby the current may always be cut off previously to the primary machine being shut down, since otherwise the latter would be driven in turn by the back current coming from the secondary machine (see Fig. 75B).

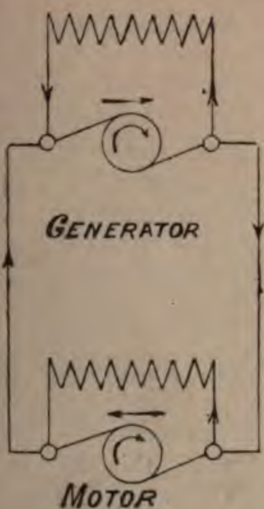


FIG. 75A.

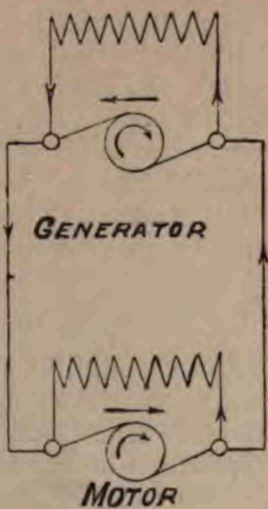


FIG. 75B.

For the same reason, in an installation where two or more shunt or compound wound dynamos worked by separate steam-engines are coupled in parallel, one of the steam-engines must not be stopped until the dynamo driven by it is put out of circuit.

3. In order to reverse the direction of rotation of a motor, it suffices to change the direction of the current either in the magnet coils or in the armature. Traction work offers the principal field for the practical application of this principle; for certain reasons it is preferable to

exclusively reverse the armature currents, thereby ensuring a current circulation through the magnet coils of invariable direction. In this way we ensure the maintenance of a sufficient degree of residual magnetism.

A singular case of interruption in the running of a combined lighting and power transmission plant may here be mentioned. A compound machine had been installed as generator, and had to supply current simultaneously to a network of lighting mains and to a shunt-wound motor, which latter worked conjointly with an auxiliary steam-engine on a common shaft. As the governor of this engine was rather inefficient, only coming into action after a somewhat large variation in speed had been produced, it frequently occurred that the engine slightly exceeded its normal speed, whereby a corresponding increase above the normal in the speed of the motor was naturally brought about. Thereby, however, the motor became momentarily transformed into a generator and sent a back current through the series winding of the primary machine, so causing a fall of its terminal pressure, with a consequent flickering of the lamps. This drawback might easily have been remedied by inserting a resistance in the shunt circuit of the secondary machine, thus increasing its normal speed.

D. Electrical Brakes.

The principle of utilising electric motors as brakes, by running them as generators upon a suitable resistance has, long been known. If the same has, nevertheless, failed to find extensive application in traction work, this may be ascribed principally to the circumstance that, owing to the extremely limited space at disposal for the speed-controlling apparatus and the necessary resistances, it is practically impossible to obtain a sufficient number of gradations in the regulating device, so as to permit of the maintenance of the required speed over any decline, irrespective of the load on the car. When too low a resistance is provided the cars will run too slowly, especially if they happen to be lightly loaded. Another peculiarity of electric brakes, frequently very prejudicial in its action, is that if the car is inadvertently allowed to attain too high a velocity before the brake action is called into play, the E.M.F. at the motor's terminals is very apt to rise considerably above its normal value. The author has

himself, in the case of tramway motors working on a 500-volt supply, not infrequently observed currents at pressures amounting to over 1,100 volts. Naturally, the insulation is very liable to suffer with such abnormal pressures. Thus if, on the one hand, we effect an economy in brake-blocks, we run a risk, on the other hand, of having to incur sooner or later an expenditure on new armature windings, etc., equivalent to double the initial saving. Nevertheless, there exist conditions under which a judicious employment of the electric brake offers certain advantages. Such an occasion offers itself, for instance, when the line in question has a constant steep slope in one direction, as does the electric tramway at Grütsch-a-Mürren (Switzerland) installed by the Oerlikon Engineering Company, where the electric brake has been in use since 1889.

If we wish to employ an electric motor as a brake, we must take it out of the distributing circuit, and short-circuit it with a suitable resistance.

The brake action of a motor is good, sometimes almost violent, but is only manifested when a velocity greater than a certain critical value has been acquired.

We will now determine what resistance will be necessary in order to conform to certain speed requirements with a given load and gradient.

The amount of work demanded from the motor running as generator is given by the equation—

$$C\,E = \frac{9{\cdot}81}{60}\,v\,P\,(\beta - \alpha)\,\zeta \quad . \quad . \quad . \quad . \quad (71)$$

Whilst ζ may be estimated with some degree of accuracy, v, C, and E are, on the other hand, unknown quantities.

With regard to E, however, there exists the known relation—

$$E = \frac{v\,a}{D\,\pi} \cdot \frac{N\,\phi}{60 \times 10^8} \cdot \frac{p}{p_1}\,(1 - \epsilon).$$

In order that we may be able to employ the ordinary velocity curve of the motor (Fig. 64), it is necessary that

$$v_1 = \frac{E_1 \,.\, 60 \,.\, 10^8 \,.\, p_1}{\phi \,.\, N \,.\, p} \cdot \frac{D\,\pi}{a}\,(1 - \epsilon).$$

By multiplying the two equations together it follows that

$$v_1 = v \cdot \frac{E_1}{E} (1 - \epsilon)^2,$$

or, if we substitute the value of E from equation (71), then

$$v_1 = E_1 \frac{(1 - \epsilon)^2}{\zeta} \cdot \frac{60\,C}{9{\cdot}81\,P\,(\beta - a)} \quad . \quad . \quad . \quad . \quad (72)$$

It suffices for an approximate calculation to set down $(1 - \epsilon)^2 = \zeta$, since in the final design a certain margin is allowed for the value of the resistance over and above that deduced from calculations. Therefore with the customary pressure $E = 500$ volts—

$$v_1 = 3{,}000 \frac{C}{P\,(\beta - a)} \text{ (approximately)} \quad . \quad (73)$$

An example may be given to illustrate the importance of this equation:

Example.—Fig. 76 represents the characteristic of a 30-h.p. Westinghouse tramway motor. Let us suppose this motor to be mounted upon a car of 8 tonnes gross weight. We proceed to determine what resistance will be necessary to ensure a speed not exceeding 240 m. per minute down a gradient of 49 in 1,000 with a full load. The terminal E.M.F. = 500 volts. Approximately speaking, $P \times (\beta - a) = 8 \times (49 - 10) = 312$.

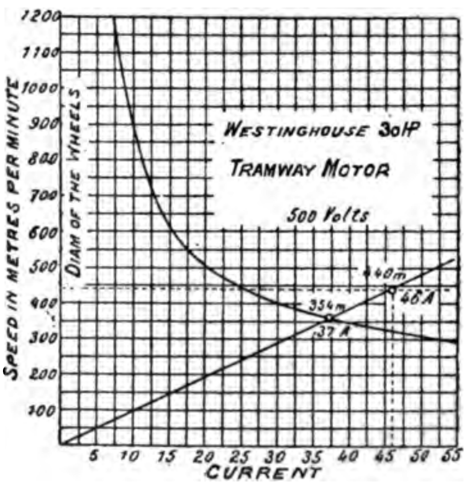


FIG. 76.

Hence, it follows that with any current C—for instance, 46 amperes—

$$v_1 = 3{,}000 \frac{46}{312} = 440 \text{ m.}$$

Plotting out this curve the point in which it cuts the velocity curve will give us the actual current, C = 37 amperes. Further, taking ζ at 0·83, then according to equation (71):

$$E = \frac{1}{37} \cdot \frac{9{\cdot}81 \times 240 \times 312 \times 0{\cdot}83}{60} = 280 \text{ volts.}$$

As a check upon our figures it remains to investigate whether this E.M.F. would actually be attained with a current of 37 amperes. The value of v_1, corresponding to 37 amperes, amounts to 354 m., according to the curve. It consequently follows that

$$E = E_1 \cdot \frac{v}{v_1} \cdot (1 - \epsilon)^2.$$

From the dimensions of the machine $\epsilon = 0{\cdot}08$, therefore:

$$E = 500 \cdot \frac{240}{354} \cdot 0{\cdot}922^2 = 288 \text{ volts.}$$

The results of the calculations are thus shown to be satisfactory. We adopt the mathematical mean E = 284 volts. There remains now only the corresponding resistance to determine; we have,

$$R = \frac{284}{37} = 7{\cdot}7 \text{ ohms.}$$

E. Alteration in the Winding of the Field Magnets in Machines already constructed.

We will at first suppose that the boring of the field magnets remains unaltered. We will subsequently indicate the modifications necessary when the air-gap is varied.

We have already shown, in a section of Chapter II., how we may calculate the necessary winding for the armature of a dynamo already made, or of one designed for any output. We there assumed a density B_l of the lines of force in the air-gap.

A further problem is to determine the field-magnet winding necessary to obtain this induction B_l, as well as ϕ.

For this purpose we only require to know the magnetisation curve for a similar dynamo of the given electrical dimensions; in that case we shall be given some of the following data, which will indicate the course to be pursued.

If the dynamo in question is *shunt wound*, a separate current not being available to excite the field magnets, we can always

include in the derived circuit a large adjustable resistance and a sensitive ammeter, after which we can revolve the armature at a constant speed as great as possible, without taking any current from the armature. The high speed is necessary to render the measurement of high degrees of saturation possible. When circumstances permit, however, a separate excitation of the field magnets is preferable. By successively decreasing the resistance in the derived circuit, and plotting a curve exhibiting the relation between the current in this circuit and the voltage measured across the brushes of the machine, or, better still, the value of ϕ, the magnetisation curve of the machine will be obtained.

Another series of experiments is made by altering the resistance of the external circuit of the machine, the excitation remaining constant, and determining the corresponding values of the terminal pressure. For this purpose the exciting current is so chosen that the terminal pressure is obtained at full load. A modification of this experiment could be made by varying the exciting current with the load in such a manner as to maintain the terminal pressure constant. But this latter method is rather more laborious, although the results obtained will subsequently be very useful in designing the regulating resistance.

Let us now consider two points on the constant excitation curve; it will be seen that the drop in pressure between the machine terminals is always greater than can be accounted for by the mere resistance of the armature. We might consider the supplementary drop in pressure as the product of the current generated into a fictitious armature resistance, though the latter is not a constant quantity. In some dynamos this fictitious resistance decreases with an increasing saturation; in other dynamos the opposite relation obtains, as may be seen from the following, deduced from experiments on three different machines:

Strength of Armature Current.		Fictitious Resistance.
3 kw.	300 amperes.	0·0021.
	900 "	0·00078.
18 kw.	50 "	0·048.
	150 "	0·04.
50 kw.	150 "	0·04.
	450 "	0·06.

As a general rule, the fictitious resistance may be considered as remaining approximately constant whilst the excitation remains unchanged, as long as the armature current does not vary very considerably.

A similar series of experiments may be made in the case of a series-wound machine, preferably with a separate field-magnet excitation, no current being taken at first from the armature, whilst the machine is subsequently loaded.

In the case of compound-wound machines, the series windings should first be short-circuited; for the rest we proceed as in the case of a shunt-wound machine.

When, owing to its form or any other circumstance, the dynamo cannot be driven by a belt, or in any similar manner, we might connect the machine with constant-pressure supply mains, and run it as a motor; in this case the ordinates of the resulting curve should represent ϕ as deduced from the terminal pressure. In order to vary the armature current, we may alter the load on the machine, which can be conveniently done by making it drive a second machine as a generator, the resistance in whose circuit may be altered at pleasure.

We will also mention another method, given in the *Elektrotechnische Zeitschrift* (June, 1888), which permits of experiments being performed on a dynamo on full load, its output being three to three and a-half times that of the motor.

For this purpose we require two dynamos. The machine to be tried is driven at its normal speed. In the circuit of this machine we include a second dynamo in series with a variable resistance.

This second machine plays the part of a motor, and restores to the primary dynamo, by means of a suitable coupling, the energy supplied to it, less the losses which take place in the machine. The methods used in winding the two machines are of no importance; on the other hand, both must have appropriate speeds and pressures. Moreover, the adjustable resistance should be furnished with numerous divisions.

It is preferable to use two dynamos of identical output, for it is only then that we can realise the appropriate experimental conditions.

We could vary the output of the dynamo to be experimented on either by enfeebling the magnetic field (by means of an

adjustable resistance included in the field-magnet circuit, in the case of shunt-wound machines) or by modifying the number of active armature conductors, or displacing the brushes (in the case of series machines).

When the choice of the method of coupling is well made, we can in this manner obtain exactly the desired effect.

Examples Relative to the Winding of Field Magnets.

Example 1.—It is required to determine the particulars of the winding of a shunt-wound dynamo to supply 120 amperes at 400 volts, the speed being 400 revolutions per minute.

Suppose that we already possess a model dynamo supplying 24 amperes at 1,720 volts, its speed being 700; we will use this for experimental purposes, and subsequently determine in what manner the armature and field-magnet windings must be modified in order to obtain the required output.

The effective output of the model machine employed is, it is true, slightly smaller than that of the machine to be constructed, but it is well to remark that dynamos which have been originally designed for high pressures, but have subsequently been rewound for low tension, are capable of developing an output from 10 to 20 per cent. greater than the primitive one. This is due in part to the smaller amount of insulation necessary under the diminished pressure, and in part to the fact that the section of the armature wires, and with this the armature current, increases with the linear dimensions.

Let us suppose that the results of experiments on the dynamo, originally furnished with a series winding and a Gramme ring armature, are as follows:

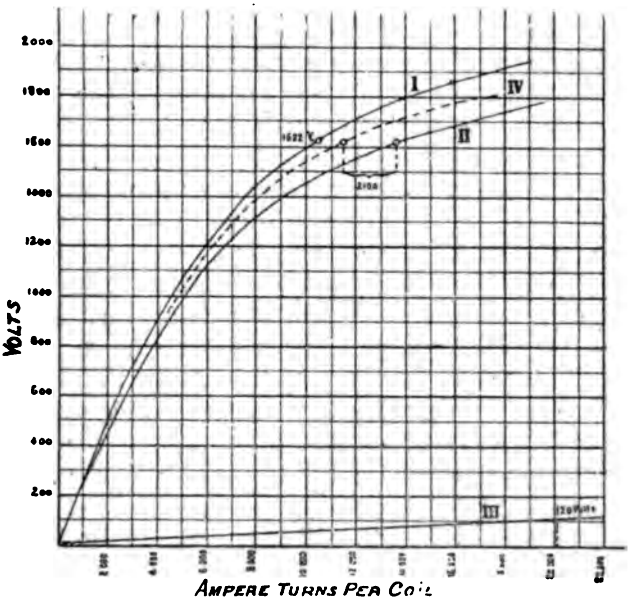
1. FIELD MAGNETS SEPARATELY EXCITED: NO ARMATURE CURRENT.

Speed.	Volts.	Ampere-Turns per Field-Magnet Coil.	Speed.	Volts.	Ampere-Turns per Field-Magnet Coil.
700	400	1,700	700	1,500	8 400
700	800	3,300	700	1,600	10,000
700	1,100	5,100	700	1,750	13,500
700	1,300	6,700	700	1,900	17,000

2. Self-Excited Dynamo.

Speed.	Volts.	Amperes.	Ampere-Turns per Field-Magnet Coil.	Ampere-Turns in the Armature.
700	740	4	3,400	2,240
700	1,230	8	6,800	4,500
700	1,480	12·3	10,500	6,900
700	1,650	17	14.500	9,500
700	1.800	24	20,400	13,400

The experimental results contained in the last two tables are graphically represented in Fig. 77.



Curve I. Separate excitation.
„ II. Self-excited machine.
Curve III. Ohmic loss.
„ IV. = I. – III.

Fig. 77.

Data Relating to Dynamos Experimented Upon: D = 510; N = 1,100. Length of armature turn = 1·2 m.; diameter of an armature wire = 2 mm.; hence the resistance of the machine between the brushes is

$$\frac{1}{2}\,\frac{550 \times 1\cdot2}{50 \times \frac{2^2\,\pi}{4}} = 2\cdot1\ \omega.$$

The resistance of the field-magnet circuit is $2 \cdot 9\ \omega$, when the wires are raised to their maximum temperature by the current flowing through them. Number of turns per bobbin $= 850$.

For a current strength of 24 amperes (Fig. 77) the drop in voltage is

$$24\,(2 \cdot 1 + 2 \cdot 9) = 120 \text{ volts.}$$

Plotting this value parallel to the axis of ordinates, above the corresponding excitation (in ampere-turns)—viz., 20,400—and connecting the point thus obtained with the origin, we shall obtain the straight line III., the ordinates of which must be added to those of Curve II.

The influence of the armature reactions on the magnetic field are here clearly manifested; indeed, if the armature reactions were negligible, the Curve II. obtained as above would coincide with Curve I., which is seen not to be the case here. For an excitation corresponding to 8,000 ampere-turns the pressure between the brushes is consequently only reduced by 60 volts, that is to say, by 4 per cent., due to the reaction of the 2,600 ampere-turns of the armature. We shall therefore commit no great error in the ensuing calculations if we suppose, for simplicity, that the drop of voltage due to the armature reactions is directly proportional to the number of armature ampere-turns. If, for instance, the armature is provided with 1,100 wires instead of 1,500, the drop of pressure will, for the same current strength in the armature as above, be equal to

$$4\,\frac{1{,}500}{1{,}100} = 5 \cdot 5 \text{ per cent.}$$

(a) Calculation of the New Armature.

We will suppose that the current density in the armature wires is equal to $3 \cdot 6$ amperes per square millimetre.

Section of wire $= \frac{120}{2} \cdot \frac{1}{3 \cdot 6} = 16 \cdot 7$ square millimetres.

Diameter of bare wire $= 4 \cdot 6$ mm. (after Table II.).

Diameter of insulated wire $= 5 \cdot 1$ mm.

The number of wires which could be wound on the

armature, supposing them to be arranged as closely together as possible, is

$$n = \frac{510\,\pi}{5\cdot1} = 314.$$

For convenience in winding, we may take this number as = 300.

(b) Calculation of the New Winding for the Field Magnets.

A pressure of 500 volts corresponds to a definite number of lines which may be calculated from equation (10). This operation is, however, unnecessary. Indeed, to be able to apply the primitive characteristic (Fig. 77) to the new machine, it is only necessary to find for what pressure the proper number of lines will be generated, and what will be the excitation necessary for this purpose.

The pressure is evidently

$$E = 400\,\frac{1{,}100 \times 700}{300 \times 650} = 1{,}580 \text{ volts.}$$

It follows from the Curve I. (Fig. 77) that the pressure will correspond to 9,700 ampere-turns when no current flows in the armature. To obtain the total excitation, we must first calculate the drop of voltage in the machine—*i.e.*,

$$e = \frac{550 \times 1\cdot2}{50 \times 16\cdot7} \cdot \frac{100}{2} = 10\cdot8 \text{ volts,}$$

or 2·7 per cent. of the total pressure. To take account of this loss, we must obtain from the Curve I. an excitation corresponding to 1,580 (1 + 0·027) = 1,622 volts. We thus obtain 10,400 ampere-turns. The Curves II. and IV. show that, in order to produce the E.M.F. of 1,622 volts, we further need, by reason of the armature reaction, a number of ampere-turns equal to 13,600 − 11,500 = 2,100, or, in all, 12,500 ampere-turns.

This calculation is not quite exact, and consequently a correction must be applied, since the number of ampere-turns was not the same in the experiments as in the projected machine. As the experimental dynamo carried 850 turns per field-magnet bobbin, we must have had,

corresponding to 13,600 ampere-turns, a current which was equal to the armature current, its value being—

$$\frac{13,600}{850} = 16 \text{ amperes.}$$

Consequently, the number of ampere-turns in the armature were

$$\frac{16}{2} \cdot \frac{1,100}{2} = 4,400;$$

whilst we shall have in the armature of the new machine on full load—

$$\frac{300}{2} \cdot \frac{120}{2} = 9,000 \text{ ampere-turns.}$$

Consequently, for the dynamo which is to receive the new winding, the excitation per field-magnet coil must be

$$10,400 + 2,100 \frac{9,000}{4,700} = 14,700 \text{ ampere-turns.}$$

An almost identical result may be arrived at by the following train of reasoning:

For a terminal pressure of 1,580 volts, the Curves II. and IV. give a drop of pressure equal to

$$1,670 - 1,580 = 90 \text{ volts.}$$

The armature in this case carries $\frac{12,600}{850} \cdot \frac{1,100}{4} = 4,100$ ampere-turns. Consequently, for 9,000 ampere-turns the drop in pressure is $\frac{9,000}{4,100}\ 90 = 197$, augmented by $1,580 \times 0{\cdot}027 = 43$ volts. From the Curve I., we obtain, corresponding to $1,580 + 197 + 43 = 1,820$ volts, an excitation of about 14,600 ampere-turns.

Example 2.—The data respecting a 3-kw. two-pole dynamo, given in Fig. 17, Plate II., are as follows:

Terminal pressure = 125 volts; current strength = 24 amperes; speed = 1,400.

Let, moreover, D = 21 cm.; l = 16 cm.; N = 424; diameter of wire = 2·2 mm. (sectional area = 3·8 sq. mm.); mean length of an armature wire = 0·52 m.; drop of pressure between the

brushes = 7 volts; number of turns per field-magnet coil = 4,700.

The results of experiments on this machine are given in Fig. 78; the Curve I. is the characteristic for open circuit, and Curve II. gives the armature current strength and the excitation for a constant terminal pressure of E = 125 volts.

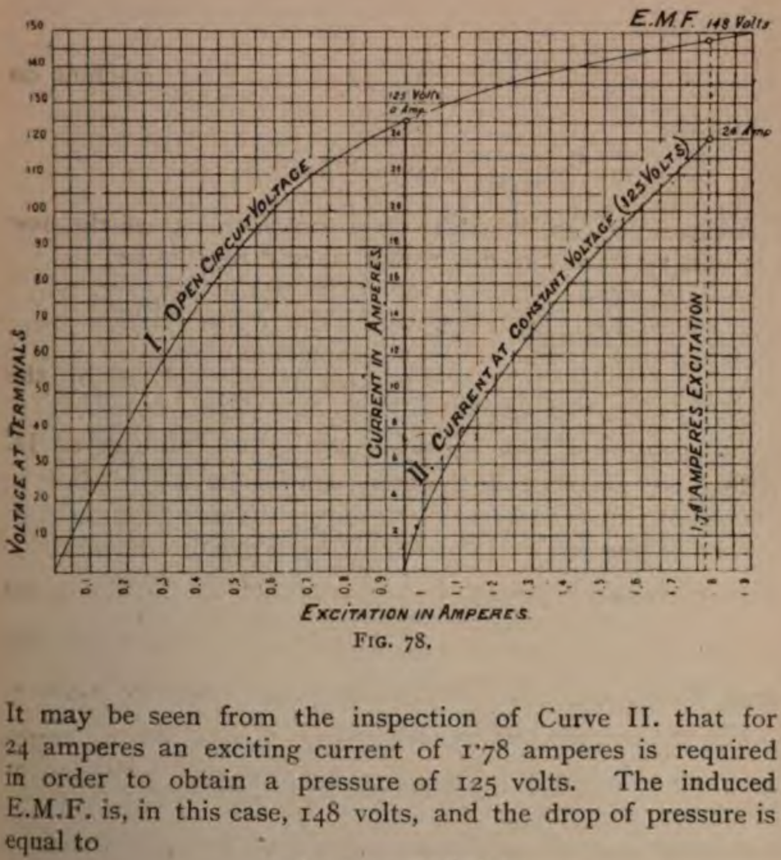


Fig. 78.

It may be seen from the inspection of Curve II. that for 24 amperes an exciting current of 1·78 amperes is required in order to obtain a pressure of 125 volts. The induced E.M.F. is, in this case, 148 volts, and the drop of pressure is equal to

$$148 - 125 = 23 \text{ volts.}$$

Of this 23 volts, 7 correspond to the loss due to the armature resistance, and 16 are due to the armature reaction.

Let us suppose that it is necessary to furnish this machine with a new winding, so that 8 amperes at a pressure of 290 volts may be obtained; the speed remaining the same, and

the degree of saturation found in the first machine being as far as possible preserved, we thus have

$$N = \frac{290}{125} 424 = 980.$$

For the same ohmic loss the section of the wires must be modified in the ratio of the current strengths; in other terms,

$$s' = s\frac{C'}{C} = 3{\cdot}8\,\frac{8{\cdot}3}{2{\cdot}4} = 1{\cdot}3 \text{ square millimetres.}$$

Let there be 53 slots; the size of one, augmented by that of a tooth, will be

$$\frac{210\,\pi}{53} = 14{\cdot}5 \text{ millimetres.}$$

Consequently the breadth of a notch must not exceed 6·5 mm.; of this breadth 1 mm. should be reserved for the insulating layer. There is only 5·5 mm. remaining, which will suffice to lodge three wires of 1·3 mm. section (bare) sectional area of each wire = 1·32 square millimetres.

Number of layers in a notch = $\frac{980}{53 \times 3} = 6{\cdot}16$, or, roughly, 6, consequently $N = 53 \times 3 \times 6 = 954$.

In order to determine the excitation for the new winding by the aid of Curve I., we must compare our new numbers with the corresponding magnitudes of the original winding; 290 volts corresponds to $290\,\frac{424}{952} = 129$ volts on Curve I. We have besides found for 24 amperes $\left(\frac{424}{2} \cdot \frac{24}{2} = 2{,}540\right.$ ampere-turns on the armature), a loss of pressure equal to 16 volts.

For the new winding we only have

$$\frac{954}{2} \times \frac{83}{2} = 1{,}980 \text{ ampere-turns,}$$

and the loss of pressure is under these conditions equal to

$$16\,\frac{1{,}980}{2{,}540} = 12{\cdot}5 \text{ volts.}$$

The ohmic loss is

$$\frac{0{\cdot}52 \times 954 \times 8{\cdot}3}{50 \times 2 \times 2 \times 1{\cdot}32} = 15{\cdot}7 \text{ volts,}$$

or, reduced in proportion to the original winding,

$$15{\cdot}7 \frac{125}{290} = 6{\cdot}8 \text{ volts.}$$

The E.M.F. produced will consequently = 129 + 12·5 + 6·8 = 148 volts (about)—that is to say, exactly the same as at first. Consequently the field magnets must receive the same number of ampere-turns as previously.

It is never possible to calculate in advance the loss in pressure due to the armature reactions of a dynamo. Hence we must content ourselves with an estimation. Toothed armatures generally give a greater loss of pressure than smooth armatures. Consequently, if in a smooth armature the loss of pressure due to armature reactions is taken as equal to the ohmic loss, the corresponding value in respect of a toothed armature must be taken of about double this value. However, this rule cannot be generally applied without certain reservations. M. Picou has, indeed, given data relative to smooth armatures in which the armature reaction is greater than the ohmic loss (see "Traité des machines dynamo-electriques). This was due to the dynamo in question requiring a considerable lead of the brushes, a characteristic which does not indicate great merit in its construction. On the other hand, the bipolar dynamos constructed in the Saint-Ouen workshop, possessing toothed armatures, give a very small loss of pressure due to the cause in question. In the type D C 18 it is equal to the ohmic loss. For the rest we must call attention to what has been said on p. 134.

F. Predetermination of the Winding of Field Magnets.

1. *Introduction.*

About a dozen years ago calculations in relation to dynamos were chiefly a matter of sentiment, and the output of a machine remained unknown until it had been constructed and tested experimentally. If the result proved favourable, the design was adopted; if, on the other hand, this was not the case, trouble was seldom taken to effect the necessary alterations indicated by the results obtained. It is natural that, under these conditions, the construction of a large dynamo involved some amount of risk which was not calculated to

encourage the development of lighting or power transmission installations. Fortunately, this unhappy state of things no longer obtains.

Calculations relating to dynamos of over 1,000 h.p. present no greater difficulty than those relating to 50-h.p. dynamos, and they can be performed with an accuracy at least as great as could be expected in the predeterminations of a steam engine or turbine.

The progress thus made is due to our superior knowledge of the laws of magnetisation, made possible chiefly by the labours of Rowland, Lord Elphinstone, Bosanquet, Forbes, Kapp, and the brothers Hopkinson.

We cannot here enter into a detailed account of the different theories which have from time to time been advanced; we must limit ourselves to a rapid survey of a few of the fundamental principles.

Rowland was the first, in his paper on "The Permeability and the Maximum Magnetisation of Iron, Steel, and Cobalt," to apply Ohm's law to magnetic phenomena (see *Phil. Mag.*, IV. Series, vol. x., Aug. 1873).

Let ϕ = the total number of lines of force circulating in a closed magnetic circuit;
R = the magnetic resistance opposed to the circulation of these lines;
M = the magnetising force = current × number of turns.

Then, according to Rowland, we have

$$\phi = \frac{M}{R}.$$

This law is of so much importance that it has served as a basis for all subsequent work. Bosanquet subsequently introduced for M the denomination "magneto-motive force," and for R the denomination "magnetic resistance" (see *Phil. Mag.*, July, 1884, p. 552; and *Electrician*, February, 1885). That physicist generalised Rowland's law, and applied it to practical problems. Thus we may determine R in terms of the magnetic resistances existing in different parts of the magnetic circuit.

In 1884 Rowland communicated to the Congress at

Philadelphia for the Advancement of Science the celebrated memoir in which a formula for the flux in a magnet was arrived at.

Let ϕ = total number of lines of force;
N_m = the number of turns of wire in the magnetising coil;
C_m = the strength of the current flowing through these N turns;
L_m = the length of the magnet core comprised between its two poles;
S_m = the sectional area of the core;
μ = the magnetic permeability;
L_l = $2\,\delta$ = double the distance between the poles and the iron of the armature;
S_l = area of the air-gap perpendicular to the flux;
S'_l = an additive term, depending on the leakage of the lines of force.

Then
$$\phi = \frac{\frac{4\,\pi}{10} \cdot C_m N_m}{\frac{L_m}{\mu\, S_m} + \frac{L_l}{S_l + S'_l}}.$$

Mr. Gisbert Kapp effected an advance of still greater importance from the practical point of view (see *Electrician*, February, 1886, to March, 1887).

To simplify subsequent calculations, that electrician as a preliminary adopted a practical unit of flux equal to 6,000 C.G.S. units (1 Kapp line = 6,000 C.G.S. lines).

Equation (10) now becomes

$$E = \phi\, N\, n\, p\, 10^{-6}.$$

In what follows, however, C.G.S. units will be used.

Let $C_m\ N_m$ = the number of ampere-turns around the magnetic circuit, whilst ϕ = the total number of lines leaving a pole. Then, after Kapp,

$$\phi = \frac{c\, C_m\, N_m}{R_m + R_a + R_l}.$$

In this formula, R_m = the magnetic resistance of the field-magnet cores and yoke, R_a = the magnetic resistance of the armature, and R_l the magnetic resistance of the double layer of air comprised by the two air-gaps; c is a constant.

Let ϕ' be the number of lines of force lost through leakage—that is to say, the number of lines which escape passing through the armature. In a sense, these lines may be said to correspond to a "magnetic short-circuit." Hence, corresponding to a total number of lines ϕ'' we shall have ϕ lines passing through the armature subject to the condition

$$\phi'' = \phi + \phi'.$$

We have, further,

$$c\,(C_m\,N_m)' = (R_a + R_l)\,\phi;$$

$$\phi' = \frac{(C_m\,N_m)'}{R'_l}\,c.$$

In this latter equation R'_l is the mean resistance opposed to the direct passage of lines of force from one pole to the other, whilst escaping the armature.

$$c\,(C_m\,N_m)'' = R_m\,\phi'';$$

$$C_m\,N_m = (C_m\,N_m)' + (C_m\,N_m)'';$$

whence

$$C_m\,N_m = \phi\left[R_m + R_a + R_l + \frac{R_a + R_l}{R'_l}\right]\frac{1}{c}.$$

To take account of the magnetic resistance of the cores increasing with the induction, Mr. Kapp introduced the hypothesis that the increasing resistance was related to the degree of saturation by means of a tangent curve, so that for 90° the saturation is complete. Thus,

$$R_m = \alpha\,\frac{L_m}{S_m}\;\frac{\tan\left(\frac{\pi}{2}\,\sigma_m\right)}{\frac{\pi}{2}\,\sigma_m}$$

$$R_a = \beta\,\frac{L_a}{S_a}\;\frac{\tan\left(\frac{\pi}{2}\,\sigma_a\right)}{\frac{\pi}{2}\,\sigma_a}$$

$$R_l = \gamma \frac{2\delta}{S_l}$$

$$R'_l = \frac{1{,}730}{\sqrt{Dl}}.$$

These formulæ apply to a dynamo with horseshoe field magnets (superior type). For dynamos with horseshoe field magnets (Edison type)—

$$R'_l = \frac{1{,}170}{\sqrt{Dl}}.$$

In these equations

$$\sigma_m = \frac{B_m}{B_{m\ max.}}; \qquad \sigma_a = \frac{B_a}{B_{a\ max.}}.$$

According to Kapp, $B_{max.}$ = 16,600 for cast iron, and 24,000 for wrought iron.

Moreover, L_m = the mean length of the lines of force in the field magnets in centimetres ;

L_a = the mean length of the lines of force in the armature breadth in centimetres ;

L_l = twice the value of a single air-gap in centimetres ;

S_m, S_a, and S_l, the respective sectional areas of the field-magnet cores, of the armature, and of the air-gap, all measured in square centimetres.

(See Figs. 81 to 86, and 98 to 102.)

We further have—

	For dynamos with wrought-iron field-magnet cores.	For dynamos with cast-iron field-magnet cores.
c =	2,400	2,000
α =	2	3
β =	2	2
γ =	1,440	1,800

TABLE OF VALUES FOR $\dfrac{\tan\left(\frac{\pi}{2}\sigma\right)}{\frac{\pi}{2}\sigma}$.

Induction per sq. cm.	Ratio of the Tangent to the Corresponding Arc.		Induction per sq. cm.	Ratio of the Tangent to the Corresponding Arc.	
	Armature.	Field Magnets.		Armature.	Field Magnets.
3,000	1·01	1·01	14,000	1·43	2·95
4,000	1·02	1·05	15,000	1·53	4·5
5,000	1·03	1·09	16,000	1·65	10·9
6,000	1·05	1·13	17,000	1·83	∞
7,000	1·08	1·17	18,000	2·04	∞
8,000	1·11	1·25	19,000	2·38	∞
9,000	1·13	1·33	20.000	2·85	∞
10,000	1·17	1·47	21,000	3·73	∞
11,000	1·22	1·65	22,000	5·27	∞
12,000	1·27	1·89	23,000	10·06	∞
13,000	1·35	2·24	24,000	∞	∞

Example.—It is required to determine the number of ampere-turns necessary for a dynamo with horseshoe magnets (Edison type, see Plate II., Fig. 2), of which the dimensions and other prescribed data are as follows:

$$
\begin{aligned}
E &= 106 \text{ volts (terminal pressure)};\\
C &= 82;\\
n &= 360;\\
N &= 328;\\
D &= 25;\\
l &= 25;
\end{aligned}
$$

$$
\begin{aligned}
L_m &= 122; & S_m &= 400;\\
L_a &= 33; & S_a &= 376;\\
L_l &= 2{\cdot}4; & S_l &= 900.
\end{aligned}
$$

The field-magnet cores are made of wrought iron. Let us suppose that the loss in the armature and field magnets is to be 15 volts. We then have

$$\phi = \frac{(106 + 15)\,60 \times 10^8}{360 \times 328} = 6{\cdot}1 \times 10^6;$$

$$B_m = \frac{6{\cdot}1 \times 10^6}{400} = 15{,}200;$$

$$B_a = \frac{6 \cdot 1 \times 10^6}{376} = 16{,}200;$$

$$B_l = \frac{6 \cdot 1 \times 10^6}{900} = 6{,}800;$$

$$B'_l = \frac{1{,}170}{\sqrt{25 \times 25}} = 46 \cdot 8.$$

The values of the tangent can be determined, by interpolation, from the preceding table (p. 148), but as the field magnets are strongly saturated, it is preferable to make the exact calculation—

$$\sigma_m = \frac{15{,}200}{16{,}600} = 0 \cdot 915;$$

$$\frac{\tan\left(\frac{\pi}{2}\sigma_m\right)}{\frac{\pi}{2}\sigma_m} = 5 \cdot 22;$$

$$\frac{\tan\left(\frac{\pi}{2}\sigma_a\right)}{\frac{\pi}{2}\sigma_a} = 1 \cdot 69 \text{ (taken from the table, p. 148).}$$

$$C_m N_m = \frac{1}{2{,}400}\Big[(122 \times 15{,}200 \times 2 \times 5 \cdot 22 + 33 \times 16{,}200 \times 2 \times 1 \cdot 69 + 1{,}440 \times 2 \cdot 4 \times 6{,}800) + (33 \times 16{,}200 \times 2 \times 1 \cdot 69 + 1{,}440 \times 2 \cdot 4 \times 6{,}800)\frac{1}{46 \cdot 8}\Big] = 23{,}000 \text{ ampere-turns.}$$

This number agrees very well with the results of experiments on open circuit (about 24,000). On the other hand, on full charge we obtain, with 23,000 ampere-turns, only 95 volts. We will content ourselves with this example.

Kapp's formulæ were for some time the only ones used by dynamo constructors in order to determine in advance, with a certain approximation to accuracy, the details of the winding of field magnets. They are, however, no longer employed, since the results obtained by their use present an insufficient accuracy. This is due to no account being taken of the quality of the iron used; moreover, the coefficients c and γ depend on the iron used in the field magnets, which is certainly not the case in reality.

2. *Hopkinson's Theory* (*Electrician*, November and December, 1886).

Let us wind a certain number, N_m, of turns of wire around an iron ring, of uniform sectional area equal to S, and mean length equal to L. If a current is caused to flow through these windings, magnetic lines of induction will be generated in the ring; these lines will not manifest themselves in any very apparent manner, but their existence can be easily proved by furnishing the ring with a second coil of a few turns, connected with a galvanometer.

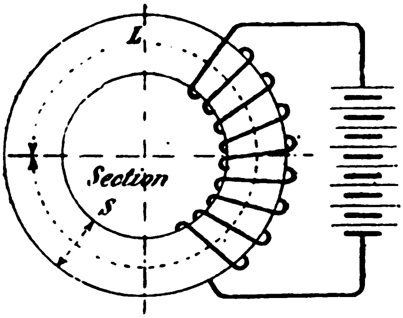


FIG. 79.

On interrupting the primitive current, the needle of the galvanometer will swing through an angle proportional to the number of lines which have been withdrawn from the secondary coil.

We may consider this iron ring to be a magnet without poles.

The total induction, ϕ, depends, on the one hand, on the number of ampere-turns, and, on the other hand, on the magnetic resistance of the circuit formed by the iron of the ring. We therefore have

$$\phi = \frac{4\pi}{10}(C_m N_m)\frac{\mu S}{L};$$

whence
$$C_m N_m = \frac{10}{4\pi}\frac{\phi}{S\mu} L.$$

We designate by μ the *specific magnetic conductivity*, or the *permeability* of the iron. Hence,

$$\mu = \frac{\phi}{S}\frac{1}{\frac{4\pi}{10}\frac{C_m N_m}{L}} \quad . \; . \; . \; . \; . \; . \; . \; . \quad (74)$$

$$= \frac{10}{4\pi} \cdot \frac{\text{number of lines per}}{\text{ampere-turns per c}}$$

The methods used for determining μ are described in Chapter IV.

When measurements are made for a great number of different current strengths, it at once becomes apparent that μ is constant only for small magnetising forces, and decreases rapidly as the saturation increases. (Exact measurements have shown that even at starting μ is not constant, but increases with the saturation; however, for all practical purposes, such variations from direct proportionality may be disregarded.) The following table gives some values of μ, determined by Dr. Hopkinson.

In manuals of electricity, $\frac{4\,\pi}{10}\left(\frac{C_m\,N_m}{L}\right)$ is generally designated by H; hence

$$\mu = \frac{B}{H}.$$

With the aid of the following table (which relates to particular samples of iron experimented on by Dr. Hopkinson) and equation (74), we may easily calculate the number of ampere-turns necessary to generate any given induction, B, provided that the section of the ring is constant:

Wrought Iron, Annealed.		Cast Iron	
B	μ	B	μ
4,650	4,650	—	—
6,200	3,877	—	—
7,750	3,031	3,870	763
9,300	2,159	4,650	756
10,800	1,921	6,200	258
12,400	1,409	7,750	114
14,000	907	9,300	74
15,500	408	10,800	40
17,000	166	—	—
18,600	76	—	—
20,100	35	—	—
21 700	27	—	—

Let us suppose that a wrought-iron ring, the mean circumference of which is equal to 21 cm., is in question. To create an induction of 18,600 lines per square centimetre, we should need

$$\frac{18{,}600}{\mu} \cdot \frac{10}{4\,\pi} = \frac{18{,}600 \times 10}{76 \times 4\,\pi} = 196 \text{ ampere-turns}$$

per centimetre length of the magnetic circuit, or, in all, $21 \times 196 = 4{,}100$ in round numbers.

Let us now consider the more general case, when the section of the ring is not uniform (Fig. 80). In this case the total magnetic resistance is equal to the sum of the magnetic resistances of the various parts of the circuit. As a consequence, we have

$$C_m N_m = \frac{10}{4\pi}\left(\frac{\phi}{S_1 \mu_1} L_1 + \frac{\phi}{S_2 \mu_2} L_2 + \frac{\phi}{S_3 \mu_3} L_3 + \ldots\right).$$

When the different parts of the magnet do not consist of the same class of iron, the values of μ must be taken from the corresponding table.

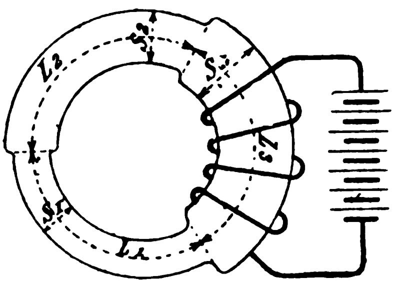


FIG. 80.

If the ring is broken at any point, the lines of induction are obliged to traverse an interval of air; two distinct poles are then formed, for the determination of which we must make use of the rules given in the first chapter. The magnetic circuit will thus acquire an additional increment of resistance, given by

$$R = \frac{L_l \, 10}{S_l \, 4\pi} \kappa.$$

There will be a leakage or spreading of the lines of force between the two poles, and in a dynamo we may distinguish between useful leakages and those which are prejudicial in their actions. As an instance of the former we may cite the case of the passage of lines of force into the armature at points outside the pole-pieces. We could take count of this by multiplying the magnetic resistance of the air-gap proper by a coefficient, κ, of which the value will be given later. This coefficient varies, according to the dimension of the poles and the bore of the field magnets, between 0·8 and 0·95.

The prejudicial influence of magnetic leakage is only of a secondary order of im[illegible]act. [illegible] lines

which pass directly from one pole to another through the air are produced by the same number of ampere-turns as those forming the useful induction; on the other hand, in those parts of the iron circuit through which these lines pass an augmented saturation will be produced, their magnetic resistance being thus increased, and consequently, with a given exciting current, the total induction will be decreased. Hopkinson took account of this fact by multiplying the saturation of these parts (calculated by the aid of the equation established for $\frac{\phi}{S}$) by coefficients, ν, ν', etc., each being greater than unity. Consequently the general formula applicable to dynamos is

$$C_m N_m = \frac{10}{4\pi}\left[\left(\frac{\phi}{S_a\,\mu_a}\right)L_a + \left(\frac{\nu\,\phi}{S_m\,\mu_m}\right)L_m + \left(\frac{\nu'\,\phi}{S'_m\,\mu'_m}\right)L'_m + \ldots + \frac{\kappa\,\phi\,L_l}{S_l}\right]$$

Table X., at the end of the book, which is taken from a memoir by Wiener, contains values of ν for almost all the usual types of dynamos (see *Electrical Engineer*, 1894). This table is extremely useful in practice, but it must be used with circumspection. It is evident that it refers to dynamos provided with smooth armatures, in which the leakage is greater than that in machines with toothed armatures. In fact, the coefficients of dispersion are greater than those published up to the present time in the different periodicals, and obtained as the results of experiments on machines with toothed armatures.

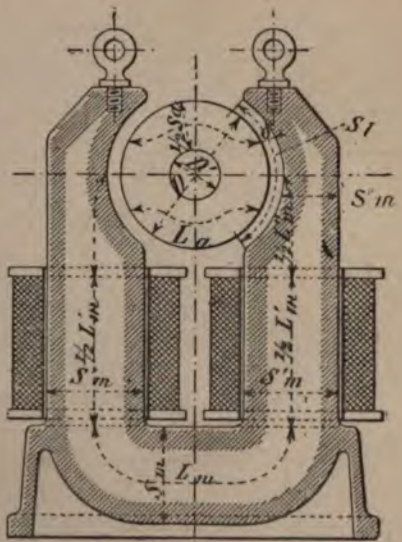


FIG. 81.

Equation (75) contains all the quantities requisite to late the ampere-turns corresponding to any given

induction. Hopkinson has transformed this equation by representing

$$\frac{\nu \phi}{S} = f(\nu B)$$

by a curve, the calculation being thus rendered more expeditious. We have

$$C_m N_m =$$

$$\frac{10}{4\pi}[f(B_m) L_m + f(B_m)' L'_m + \ldots f(B_a) L_a + B_l 2\delta].$$

In this equation it is necessary to remember that

$$B_l = \kappa \frac{\phi}{S_l}.$$

Plate I., at the end of this book, gives a general idea of the curves $f(B)$ for iron of different qualities, the results

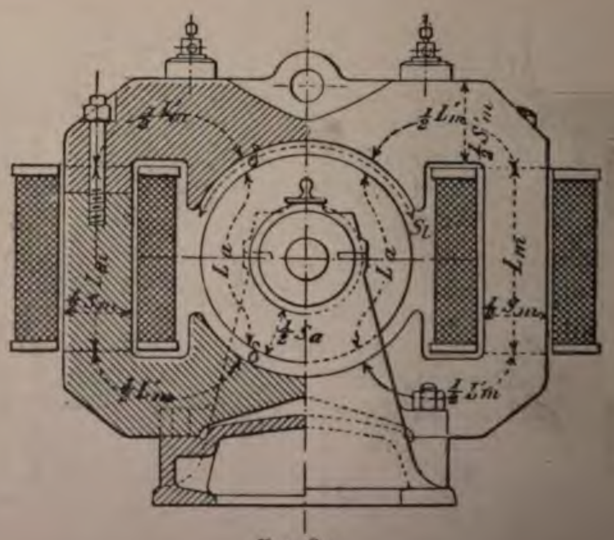


FIG. 82.

being obtained partly from data published by Dr. Hopkinson and partly from the results of experiments perf
author.

In order to avoid any possibl
terms used in connection with

explain their application to a number of well-known types of machines.

Figures	81	82	83	84	85	86	87
Number of magnetic circuits	1	2	2	4	4	—	1
Number of magnetic circuits for each pole..	1	2	2	2	2	2	1

As we *always denote by ϕ the total number of lines of induction per pole*, we will introduce S, denoting the sections of all the derived magnetic circuits obtaining their induction from the same pole.

On the other hand, equations (75) and (76), as well as those of Kapp, give the number of ampere-turns for the magnetic circuit. We shall therefore have

In the case of Fig.	81	82	83	84	85	86	87
Ampere-turns per coil	$\frac{1}{2}C_mN_m$	C_mN_m	$\frac{1}{2}C_mN_m$	$\frac{1}{2}C_mN_m$	C_mN_m	$\frac{1}{2}C_mN_m$	$\frac{1}{2}C_mN_m$

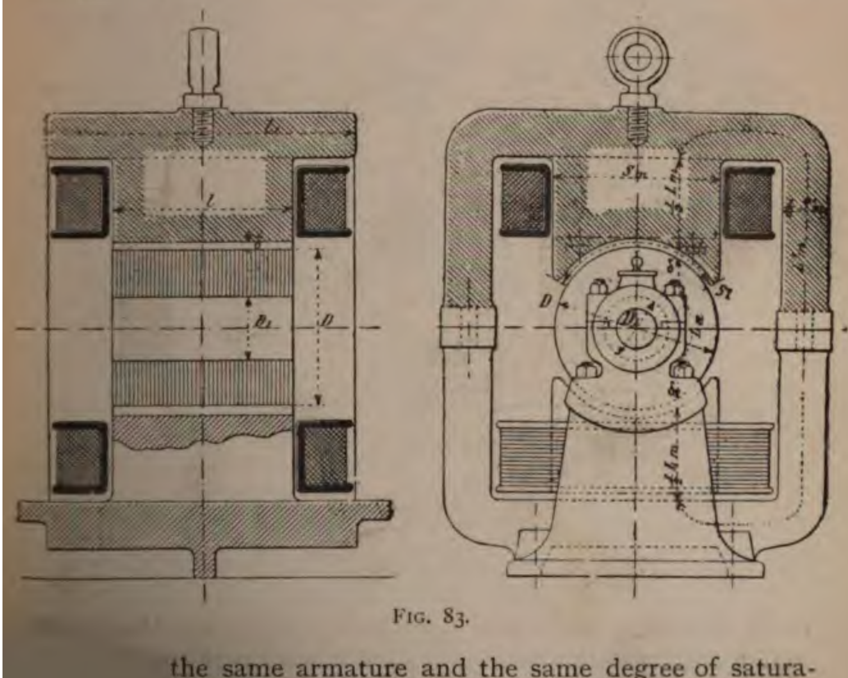


FIG. 83.

the same armature and the same degree of satura- ld magnets to be employed, the type of machine Fig. 81 will require a little more iron and a than the type represented in Fig. 82.

For the proportions generally used, the types 82 and 83 will have to within a little the same weights of iron and copper, provided that special pole-pieces are not used in 83; in the latter case an economy of copper will be effected. But when it is required to determine a dynamo of minimum weight, irrespective of its form, we might give a smaller weight of iron to the type 82.

Plate II. shows nearly all the characteristic types of field magnets arranged systematically (but not chronologically), and giving the name of the first person to use each type.

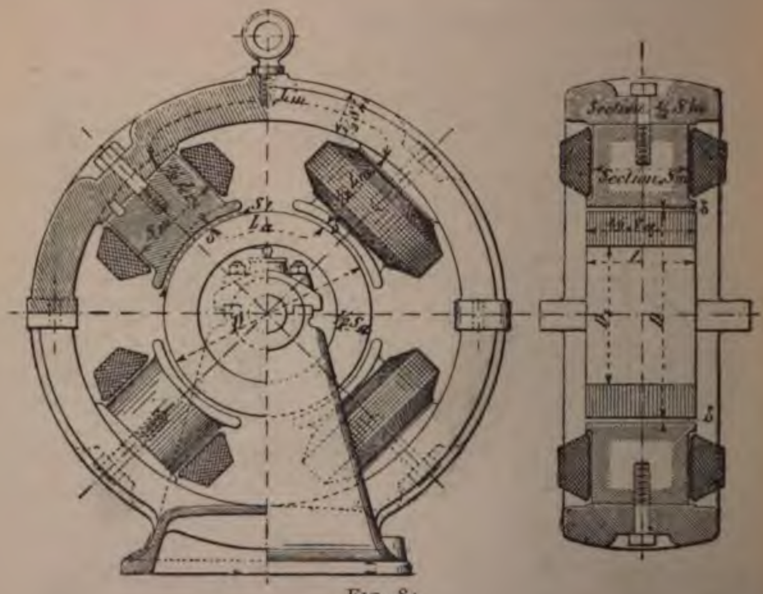


FIG. 84.

In this connection we may dispense with detailed descriptions, since perspective views are given in almost all works on electricity. We will only remark that the types 13, 14, 18, and 22 (Plate II.) are often completely enveloped by the body of the field magnets.

In a certain number of these types it has been necessary to reduce the armature reaction as much as possible by methods which will be explained in detail in Chapter VI. The types 17, 21, and 30 have been specially constructed from this point

of view, as well as the Couffinhal dynamo, of which a cut is given in Chapter IX.

Determination of δ and S in the case of Toothed or Tunnelled Armatures.

The exact determination of the air-gap, δ, in the case of toothed or tunnelled armatures presents the difficulty that it does not solely depend on the form and the number and dimensions of the slots or tunnels, but also to a considerable extent on *the degree of saturation of the iron of the armature.*

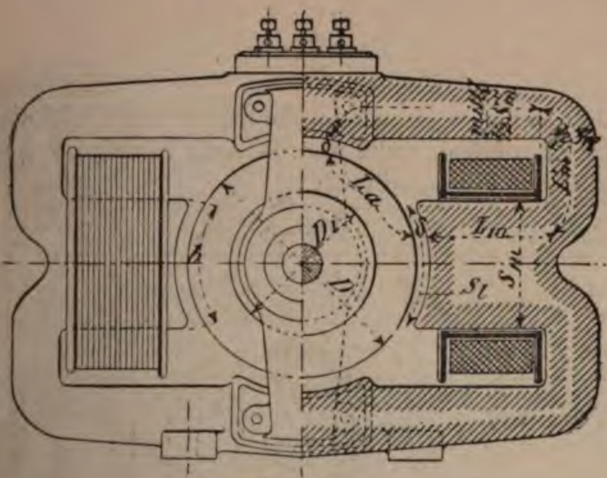


FIG. 85.

A simple train of reasoning will clearly demonstrate that this is so. Since the air offers a resistance to the passage of lines of force which varies between 200 and 1,000 times that of the iron, according to the degree of saturation of the latter, it is evident that the lines of force will not be distributed uniformly over the periphery of the armature, but will be concentrated in the teeth, a much smaller number passing into the separating slots.

In the case of toothed armatures, we may take

$$\delta = 0{\cdot}5 \text{ to } 0{\cdot}6\ u;$$

$$u = 0{\cdot}5\ u_1 \text{ (approximately).}$$

In this case we shall have

$$\delta' = 1{\cdot}1\,\delta;$$

and
$$S'_l = \frac{u + u_2}{2\,u_1} S_l = 0{\cdot}75\,S_l\,.$$

These formulæ are not, however, quite exact, since the lines of force are not perpendicular to the pole surfaces. The real mean section is slightly augmented in this manner, and it will be still more so when we take account of the flux passing into the interior of the slots. Substituting, in equations (75) and (76) for δ the double air-gap, and calculating B_l by the aid of the equation

$$B_l = \frac{\phi}{S_l} = \frac{\phi}{b_l},$$

we obtain a value of B_l which should still be multiplied by a coefficient κ', of which the approximate value may be found in the following empirical table :

VALUES OF κ'.

Breadth of Slots, in Cubic Centimetres.	Air-Gap, δ, in Centimetres.					
	0·3	0·4	0·5	0·6	0·7	0·8
0·4	1·3	1·27	1·24	1·2	—	—
0·6	1·34	1·31	1·27	1·24	1·2	—
0·8	—	1·37	1·34	1·30	1·26	1·23
1·0	—	—	1·36	1·32	1·28	1·24
1·2	—	—	—	1·35	1·30	1·26

For slots which are half closed it will suffice to augmen B'_l by from 15 to 20 per cent., whilst in the case of tunnelled armatures no contraction of the flux is produced.

This last type of dynamo appears to have been completely abandoned during the last few years. In a similar manner, although to a less extent, smooth armatures have been replaced by those with teeth.

The advantages which these latter present are of two sorts: (1) Greater mechanical strength ; (2) smaller amount of copper necessary in winding the armature.

Even when the slots ha
the iron discs are imperfe

other, thus entailing an unnecessary dissipation of energy, the cost of production is still less than when smooth armatures are employed. Toothed armatures are, however, often chosen on purely mechanical grounds. On the other hand, in the case of high-pressure dynamos, which are generally provided with a Gramme ring, the advantage of an economy of copper becomes secondary in comparison with the numerous advantages appertaining to a smooth armature—including possibility of providing a better insulation, smaller armature reactions, and consequently a diminished lead of the brushes, a simple construction, etc.

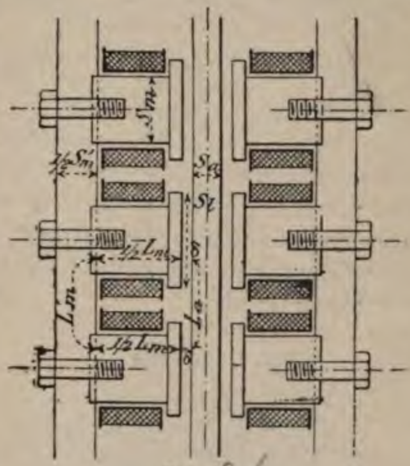


FIG. 86

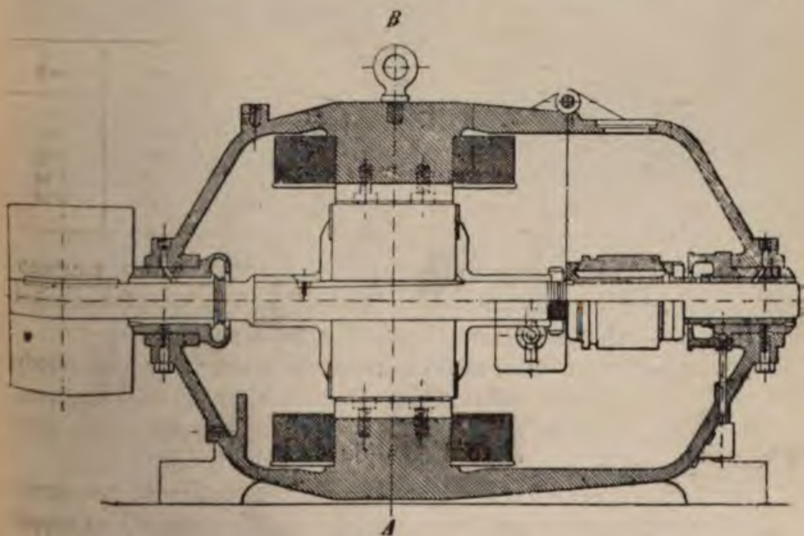


FIG. 87.

Toothed armatures become greatly heated when the discs

have not been carefully filed to remove all burrs after their stamping or milling has been performed.

Determination of κ, the Coefficient of Useful Leakage.

As the ampere-turns corresponding to the air-gap always represent the most important fraction of the total excitation, the coefficient κ plays a part which cannot be neglected. In previous editions of this work some data as to the approximate value of this coefficient were given, but it has since appeared advisable to establish a formula for κ in a rigorous manner.

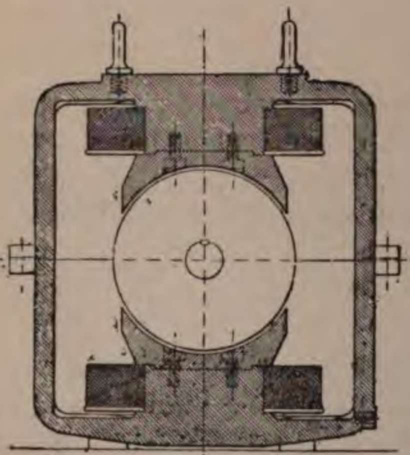


FIG. 88.

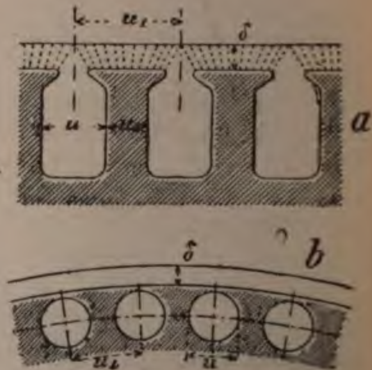


FIG. 89.

Let ϕ = the total number of useful lines which enter the armature;

ϕ_1 = the total lines leaving a pole surface;

ϕ_2 = the total lines of the two leakage fields respectively to right and left of the poles (see Fig. 90);

L_1 and L_2 = their respective conductivities;

l = length of armature.

We shall then have

$$\phi = \phi_1 + \phi_2.$$

Then the well-known analogy between the laws governing

electric currents and those which apply to the magnetic field show that the total magnetic conductivity is equal to the sum of the individual conductivities, or

$$\Sigma\, L = \Sigma\, \frac{1}{R} = \frac{1}{\kappa'\,\kappa\,\frac{10}{4\,\pi}\,\frac{\delta}{b\,l}} = L_1 + L_2 \quad . \quad . \quad (77)$$

We have determined L_1 in a preceding chapter. Its value in terms of the data given in Fig. 90 is

$$L_1 = \frac{4\,\pi}{10}\,\frac{b\,l}{\delta}\,\frac{1}{\kappa'} \quad . \quad . \quad . \quad . \quad . \quad . \quad (78)$$

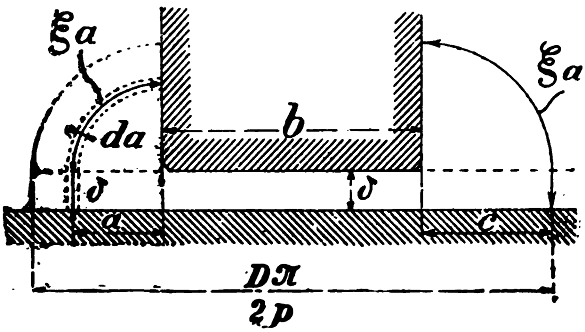


FIG. 90.

In relation to the leakage lines, we will suppose that these are grouped on either side of a pole, following arcs of circles of which the radii are equal to the distance from the pole corner, a subsequent straight element being added equal to the air-gap, δ. Let $\xi\, a + \delta$ = the length of the lines of force; ξ should receive the following values, according to the angle α which the pole surface makes with the armature :

$$\alpha = 90^\circ, \qquad \xi = \frac{\pi}{2};$$

$$\alpha = 120^\circ, \qquad \xi = \frac{2}{3}\,\pi;$$

$$\alpha = 150^\circ, \qquad \xi = \frac{5}{6}\,\pi;$$

$$\alpha = 180^\circ, \qquad \xi = \pi.$$

Consequently, for any particular element of the field at a distance a from the pole corner, the conductivity is

$$d\,L_2 = 2 \times \frac{4\,\pi}{10} \frac{l\,d\,a}{\xi\,a + \delta},$$

whence the total conductivity is given by

$$L_2 = 2 \times \frac{4\,\pi}{10}\,l \int_{a=o}^{a=c} \frac{d\,a}{\xi\,a + \delta} = 4{\cdot}6 \times \frac{4\,\pi\,l}{10\,\xi} \log_{10}\left(\frac{\xi\,c}{\delta} + 1\right). \quad (79)$$

Substituting in (77) the respective values of L_1 and L_2 by the aid of equations (78) and (79), κ can be determined.

$$\kappa = \frac{1}{1 + \frac{\kappa'}{b} \cdot \frac{\delta}{\xi} \times 4{\cdot}6 \log_{10}\left(\frac{\xi\,c}{\delta} + 1\right)} = \frac{1}{1 + \frac{\kappa'}{b}\,x}. \quad (80)$$

Plate IX. at the end of this book contains the values calculated for x, and should be found useful in the study of the dynamo.

Example.—Let us suppose that the bore of a dynamo with a smooth armature ($\kappa' = 1$) is equal to 32 cm.; the pole arc = 35 cm.; $c = 7{\cdot}5$ cm., $\delta = 1{\cdot}2$ cm., and $a = 150°$.

Table IX. gives for these values

$$x = 2{\cdot}62\,;$$

and consequently

$$\kappa = \frac{1}{1 + \frac{x}{b}} = \frac{1}{1 + \frac{2{\cdot}62}{35}} = 0{\cdot}93.$$

For dimensions not contained in that table, the value of x may be obtained either by interpolation, or, that which is often more simple, by the aid of equation (80).

Determination of the Leakage Loss.

In order to take account of the loss by leakage we will use Fig. 91, where the dotted lines [illegible] nt the flux lost by leakage.

It is evident that the sec [illegible] st number of lines, since it is [illegible]

hand, this number is diminished in passing through the ure as well as through the field magnets, since, suitable being open, a large number of lines form short-circuits gh the air.

consequently, ϕ denotes the flux emanating from a pole entering the armature, and $x\ \phi$ the loss between the n I. and the armature, the total number of lines which be generated is

$$\nu\,\phi = \phi\,(1 + x).$$

e coefficient ν could be determined by calculation or imentally.

the latter purpose one or more turns of wire are made round each of the sections I., II., III.; these coils must be capable of being connected with a ballistic galvanometer through an adjustable resistance. The two coils, III., should be grouped in series. After having connected either of the three coils with the galvanometer, we shall obtain, on quickly breaking the magnetising circuit (or, better, versing the latter), a throw of the needle which will be rtional to the total number of lines of force which have he secondary circuit. If d I., d II., d III. represent the nometer throws thus obtained; then for section I.,

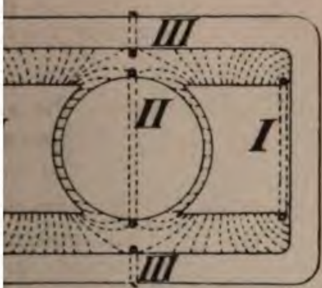


FIG. 91.

$$\nu = \frac{d\,\text{I.}}{d\,\text{II.}}\,;$$

or section III.,

$$\nu = \frac{d\,\text{III.}}{d\,\text{II.}}\,.$$

e value thus obtained is occasionally less than unity. at case it is possible to reduce the sectional area of nonding part of the magnetic circuit.

ming experiments, such as the above for other he machine, it will be found that ν is altered, naximum value is different for different types

Nevertheless, we could suppose, without committing any very great error, that ν is constant for a certain length. The magnetic circuit could thus be divided into a number of sections, the theoretical value of B may be calculated for each of these, and, finally, the numbers so obtained are multiplied by the coefficients ν_1, ν_2 ν_3, etc.; these may approximately be determined from the maximum value.

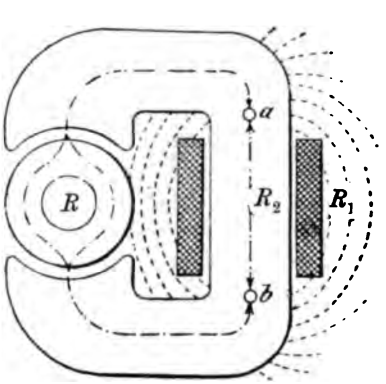


FIG. 92.

Hence, to determine the loss due to leakage, we must pursue the following course:

Let us suppose that the primary poles of the magnetic circuit are found at a and b (Fig. 92), the subsequent paths of the flux being taken as in different elements of the circuit connected in parallel. Let ϕ represent the useful lines which pass through the element $a\ R\ b$, and let $\nu\ \phi$ represent the total number of lines passing between a and b. The lines lost will therefore amount to $(\nu - 1)\ \phi$.

Let us denote the magnetic resistances of the different circuits as R_1, R_2, R_3.

In accordance with what has already been explained, the lines of force traversing the armature are determined by

$$C_m\ N_m = R\ \phi + R_2\ (\nu\ \phi).$$

This may also be written

$$C_m\ N_m = R_2\ (\nu\ \phi) + R_1\ (\nu - 1)\ \phi,$$

since the leakage field is produced with the same number of ampere-turns.

Equating the above values, we obtain

$$R_1\ (\nu - 1)\ \phi = R\ \phi;$$

whence $$\nu = \frac{R}{R_1} + \qquad R_1)$$

Numbers sufficiently accu

by substituting for R the resistance of the air-gap, $\frac{2\,\delta}{S_l}\kappa$; to determine R_1 we must use the following method suggested by Prof. Forbes (*Journal*, Society of Telegraph Engineers, xv., 551, 1886, and *Electrician*, December, 1886).

Let L_1, L_2, L_3 represent the values of the reciprocals of the resistances of the several leakage fields, of which the total resistance = R_1. To determine L_1, L_2, L_3, etc., one or other of the following methods must be employed, according to circumstances:

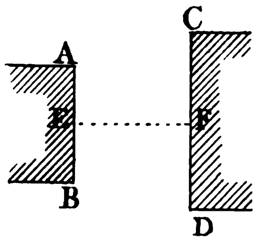


FIG. 93.

(*a*) Between two opposed parallel and nearly equal surfaces (Fig. 93), the conductivity in air is equal to the mean of the areas of the two surfaces divided by the distance separating them, the measurements being all given in centimetres.

$$L_1 = \tfrac{1}{2}\,\frac{A\,B + C\,D}{E\,F}\,a, \quad . \quad . \quad . \quad . \quad (82)$$

a being the length of the surface in a direction perpendicular to the plane of the paper.

(*b*) If the two surfaces are situated in the same plane (Fig. 94), and if their distance apart is not greater than a certain value, we have

$$L_2 = \frac{a}{\pi}\,\log_e \frac{r_2}{r_1} = 2{\cdot}3\,\frac{a}{\pi}\,\log_{10}\frac{r_2}{r_1} \quad . \quad . \quad . \quad (83)$$

$$r_2 = O\,A,\ r_1 = O\,B.$$

(*c*) In the case where the distance dividing the planes exceeds the above-mentioned limit (Fig. 95), we may apply the formula:

$$L_3 = \frac{a}{\pi}\,\log_e \frac{\pi\,A\,B + 2\,O\,A}{2\,O\,A} = 2{\cdot}3\,\frac{a}{\pi}\,\log_{10}\frac{\pi\,A\,B + 2\,O\,A}{2\,O\,A}. \quad (84)$$

The total conductivity is

$$L = L_1 + L_2 + L_3 = \frac{1}{R_1} \quad . \quad . \quad . \quad . \quad (85)$$

methods above indicated will completely suffice

for the solution of any problem occurring in practice. When the leakage is propagated through the exciting coils of the field magnets, it is necessary to remember that only one part of the exciting coil produces the leakage flux. In lieu of a more complete and complicated calculation, we may take the conductivity in this case as equal to half that obtained by the above methods.

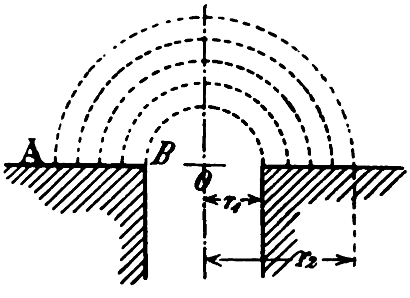


FIG. 94.

Example.—We will apply the above methods to calculate the leakage in a bipolar continuous-current motor with vertical horseshoe magnets (superior type), Fig. 96.

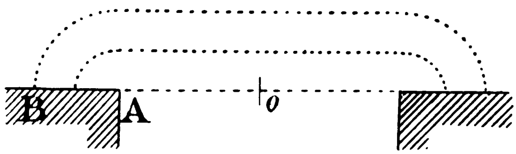


FIG. 95.

(*a*) Leakage between A and B, and between C and D (case *c* above), inside the exciting coil:

$$L_1 = \tfrac{1}{2} \times 2 \times \frac{19}{\pi} \times 2{\cdot}3 \log_{10} \frac{\pi \times 85 + 2 \times 4{\cdot}5}{2 \times 4{\cdot}5} = 8{\cdot}3$$

(*b*) Leakage between A and B, and between C and D (case *c*), above the exciting coil:

We have approximately

$$L_2 = 2 \times \frac{18}{\pi} \times 2{\cdot}3 \log_{10} \frac{\pi \times 7 + 2 \times 7}{2 \times 7} = 10{\cdot}8$$

(*c*) Leakage E F (case *a*) from interi[illegible] oil:

$$L_3 = \tfrac{1}{2} \times 1 \text{[illegible]}$$

(*d*) Leakage G H (case *c*) :

$$L_4 = \frac{12}{\pi} \times 2{\cdot}3 \log_{10} \frac{\pi \times 5 + 2 \times 4{\cdot}5}{2 \times 4{\cdot}5} = \underline{3{\cdot}8}$$

$$L = L_1 + L_2 + L_3 + L_4 \qquad = 35{\cdot}6$$

$$R_1 = \frac{1}{35{\cdot}6} \times \frac{10}{4\pi}.$$

Taking account of the magnetic resistance of the cast iron (μ = 100 about), we find

$$R = \frac{10}{4\pi}\left(\frac{1}{14 \times 12} + \frac{2 \times 15}{8{\cdot}5 \times 12 \times 100}\right) = \frac{10}{4\pi} \times 0{\cdot}009.$$

$$\nu = 1 + \frac{R}{R_1} = 1 + 0{\cdot}009 \times 35{\cdot}6 = 1{\cdot}32.$$

This single example will show that the engineer designing a dynamo has a certain amount of latitude, and that the final result will depend to some extent on his individual ability.

To avoid unnecessary complications, we only obtain, as a general rule, the leakage coefficient for that part of the magnetic circuit which is covered by the exciting coils, the rest of the leakage being neglected.

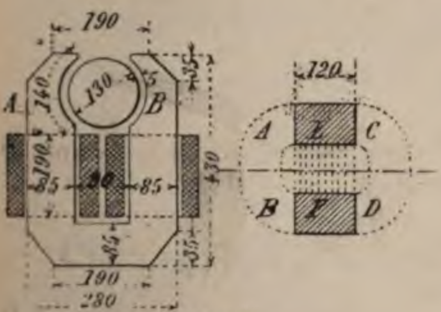


Fig. 96.

A glance at Table X. at the end of the book will show that the leakage coefficient varies very much with the type of dynamo, and that it sometimes attains a very high value. However, it would be unwise to attach too much importance to this fact ; indeed, the magnetic resistance of the parts submitted to the leakage field was relatively small in comparison with the total magnetic resistance, whilst the exciting current attained only a small percentage of the total current.

Leakage, consequently, plays only a secondary part in comparison with the other particulars, mechanical and electrical, which characterise the different types of dynamos.

Examples Concerning the Calculation of the Winding of Field Magnets.

(*a*) *Alterations in an Existing Machine.*—We have already shown in what manner the winding of a dynamo may be determined, using the curves obtained for another machine in which the bore of the field magnets is similar. In the case of smooth armatures this condition cannot always be fulfilled. According to the style of winding employed, we might find it necessary either to increase the bore, or, on the other hand, we may be able to decrease the air-gap, owing to the armature windings being executed with finer wire. As in these cases we only alter the magnetic resistance of the air-gap, the resistance of the rest of the magnetic circuit remaining constant, we can easily determine, by known methods, the necessary alterations in the excitation.

Let $(C_m N_m)$ = total number of ampere-turns for the air-gap δ_1;

$(C_m N_m)'$ = total number of ampere-turns for the air-gap δ_2;

κ and κ' being the leakage coefficients;

$B_l = \frac{\phi}{S_l}$ = the induction in the air-gap.

We have

$$(C_m N_m)' = (C_m N_m) - \frac{10}{4\pi} \kappa \kappa' B_l 2\delta + \frac{10}{4\pi} \kappa \kappa' B_l 2\delta_2. \quad (86)$$

κ and κ' will vary in value according to the size of δ, but if δ_1 and δ_2 do not differ very greatly in magnitude no very serious error will be committed in taking the leakage coefficients as equal in the two cases. Equation (86) thus reduces to

$$(C_m N_m)' = (C_m N_m) - \delta\, 1{\cdot}6\, \kappa \kappa' B_l (\delta_1 - \delta_2). \quad . (87)$$

Example I.—In the case of the 3-kw. dynamo which has already been considered (p. 140, Fig. to 3 mm. Supposing that the new ma ar- an air-gap of 4 mm., it is required of ampere-turns that will suffice

For 148 volts, we have

$$\phi = \frac{148 \times 60 \times 10^8}{1,400 \times 414} = 1,500,000.$$

Let $$S_l = b \times l = 22 \times 16 = 352;$$

$$\therefore B_l = \frac{1,500,000}{352} = 4,250.$$

We will now determine κ and κ'.

For $a = 180°$, $c = 6$ cm., we have, corresponding to $\delta_1 = 3$ mm., the value of $\kappa = 0·964$; corresponding to $\delta_2 = 4$ mm., the value of $\kappa = 0·956$.

The small difference between these values will permit us to take κ = constant = 0·96.

Similarly, κ' = constant = 1·3.

Hence from equation (87) we have

$$(C_m N_m)' = 8,360 - 1·6 \times 0·96 \times 1·3 \times 4,250 (0·3 - 0·4)$$
$$= 8,785 \text{ ampere-turns.}$$

It is often advantageous to obtain for the new dynamo with its modified air-gap, not only isolated relations such as those determined above, but the entire characteristic of the machine. For this purpose we calculate the value of the factor $\kappa \kappa' \times 1·60\ B_l\ (\delta_1 - \delta_2)$ for any value whatever of B_l, provided it is sufficiently large. We now plot this value parallel to the axis of abscissæ, as shown in Fig. 97.

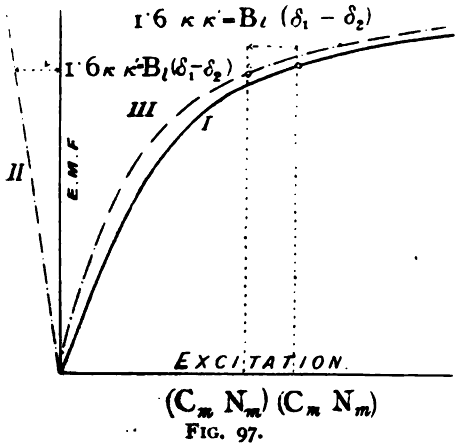


FIG. 97.

... point thus obtained by a straight line with
... $> \delta_2$ we reduce the abscissæ of Curve I.
...t line thus obtained; when $\delta_1 < \delta_2$ we
...e straight line and curve, then the
...ified machine is obtained.

Example 2.—The electrical engineer is often called on to solve the following problem: *A motor is found from experiment to run at a smaller speed than that for which it has been designed; it is required to increase its speed to that for which the design was made.*

When the difference between the speeds is not very great, and when the motor in question possesses a shunt winding, the solution of the problem is given at once: ϕ must be diminished by duly increasing the air-gap. In case of a series-wound motor, one or other of the following methods may be used: (1) A part of the field-magnet winding may be unwound; or (2) the air-gap may be increased. Both methods are often employed at once. The unwinding of the magnet coils presents the disadvantage that it may lead to sparking at the commutator; on the other hand, when the air-gap is very much increased, the leakage is augmented, but the lead of the brushes and the sparking become less. The diameter to which the bore of the field magnets should be increased is easily calculated from the results of the following experiment: The motor is run with the prescribed current strength and terminal voltage, and the excitation is varied by means of an adjustable resistance till the speed acquires its proper value; (in the case of a shunt-wound machine, the resistance is inserted in the field-magnet circuit; in the case of a series machine, the adjustable resistance is connected in parallel with the field-magnet windings). We thus obtain two different excitations — the first without resistance, corresponding to a reduced speed; the second with a resistance inserted, corresponding to the required speed. The difference between these excitations is now to be compensated by means of an increase in the size of the air-gap.

Let B_l be the induction in the air-gap for the normal speed, and $(C_m\ N_m)''$ the difference between the ampere-turns of the exciting circuit in the above two experiments. The increase in the air-gap is given by

$$\delta' = (C_m\ N_m)'' \frac{4\ \pi}{10} \frac{1}{B_l},$$

or the diameter of the magnet borin[g] by $2\,\delta'$.

When the exciting circuit and the air-gap are both simultaneously modified (in the case of a series motor), we denote by $(C_m\ N_m)''$ in the above formula that part of the excitation which is not compensated for by an alteration in the winding.

(*b*) *Calculation for a Dynamo to be Constructed.*—We will limit ourselves to illustrating, in two examples, how the formulæ established above may be applied to any particular case. We will avoid that side of the question which has already been treated of in Chapter II.

As a matter of fact, the dimensions and winding of the armature are determined simultaneously with those of the field magnets, and the dimensions of the armature cannot be considered as finally settled until appropriate dimensions have been determined for the field magnets. Although the methods previously described leave the engineer a great deal of latitude in the course to be followed, yet it is well to recognise from the commencement what path it would be most rational to select.

After having determined the approximate dimensions of the armature by the aid of the equations (50) to (53), or, better, after these approximate dimensions have been assumed from the results of previous experience, we pass on to the determination of the number of wires, N, assuming a certain number of ampere-turns per centimetre length of the periphery of the armature. We have

$$N = \frac{k\ 2\ p_1\ D\ \pi}{C}.$$

At this point the tables on pp. 78 and 79 can be consulted; k varies according to the size of the machine, between very wide limits; from 60 to 150 and more.

In place of the above procedure, we might equally well make use of the equations (47) and (48) and calculate the approximate diameter of the wire, verifying our results by the aid of a rough drawing (p. 68) illustrating the method by which the wires may be disposed around the armature; it
…med that in small dynamos, k will not exceed 80
… whilst for large machines it will approximate

…n designed, the space reserved for its

reception being approximately calculated; and the air-gap being decided upon, the number of ampere-turns necessary to produce the required flux is calculated.

In order that the machine should work with a certain stability (p. 81) the ampere-turns for the rest of the magnetic circuit should be about equal or slightly superior to those necessary for the air-gap. This reasoning permits us to adopt appropriate sections for the field magnets.

This calculation is verified by making a comparison between the ampere-turns of the armature and those of the field magnets. The first are calculated for a given magnetic circuit from the formula:

$$\text{Ampere-turns of armature} = \frac{C\,N}{4\,p\,p_1}.$$

The ampere-turns of the field magnets are given by C_m N_m.

For ordinary borings C_m N_m should be between two and four times the number of ampere-turns of the armature. The dimensions of the field windings must therefore be chosen with due regard both of their relation and of the space at our disposal for the reception of the exciting coils. This latter point may be verified by the well-known formulæ (pp. 87 and 88). Equation (27) may also be used to check our results.

When, by means of repeated changes in the dimensions and winding, we have obtained results sufficiently consistent, and when the losses in the various circuits do not differ much from those which were initially prescribed, a final calculation of the winding may be made. But the task of calculating is not even then finished. The resulting machine would indeed fulfil to within a little all the conditions as to output and working, but it is not at all certain that the sparking would not be excessive.

But as we are at present occupied with the winding of the field magnets, the above points may suffice; the verification of a design, taking account of the sparking, will be considered in a special chapter (Chapter VI.)

Example 1.—It is required to construct a bipolar series-wound dynamo of 4·5 kw., the speed being 1,200, and the general form being given in Figs. 98 and 99.

Let $E = 125$ volts.

$C = 36$ amperes.

$D = 20$ cm.; $l = 18$ cm.

The armature is to be toothed.

Number of slots = 60.

Number of wires per slot = 4, and therefore N = 240.

Diameter of bare wire = 3·2 mm.; with insulation = 3·9 mm.

Section of wire = 8 sq. mm.

Mean length of an armature turn = L = ·55 m.

It follows that the fall in pressure will be

$$0{\cdot}55 \times \frac{240}{2} \times \frac{36}{2} \frac{1}{50 \times 8} = 3 \text{ volts.}$$

Let us suppose that the drop in pressure due to the armature reaction is equal to 10 volts.

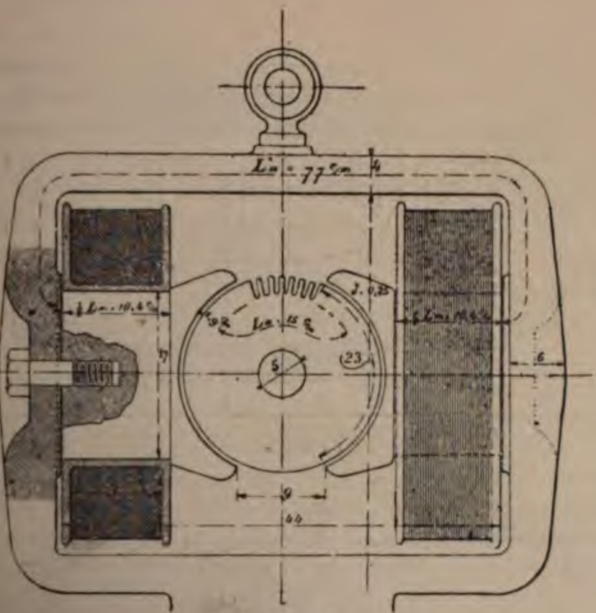


FIG. 98.

In order to proceed with security, and preserve a sufficient for regulation, we will take 15 volts as the total fall in "hen

$$\frac{(125 + 15) \times 60 \times 10^8}{240 \times 1{,}200} = 2{,}900{,}000.$$

Calculation of the Field Magnets.—It follows from Table X. that $\nu = 1{\cdot}18$ for the core of the field magnets. The leakage is naturally modified by the length of the rectangular yoke (external magnetic circuit). We will take account of this by augmenting the section of the circuit outside the exciting coils, and taking throughout $\nu = 1$.

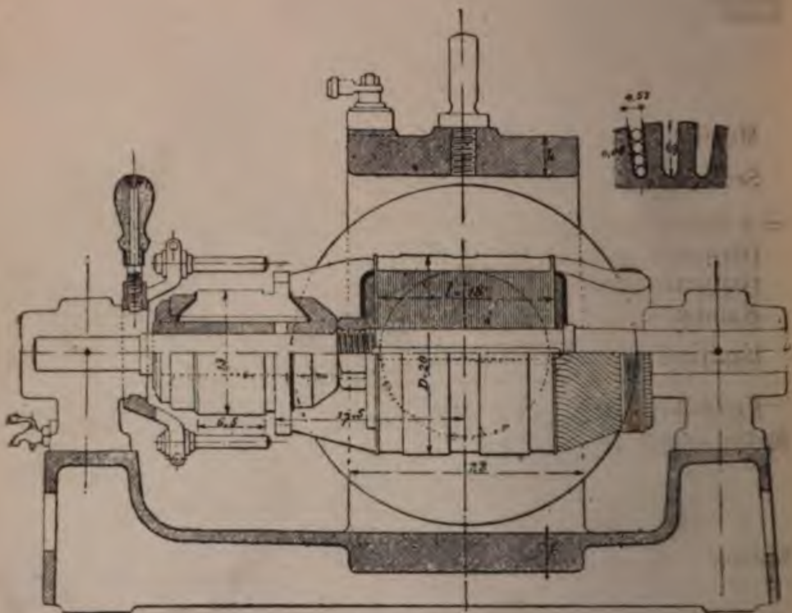


FIG. 99.

To determine the poles we may refer to Table IX.

$$\alpha = 180,\ c = 4{\cdot}5 \text{ cm.}:$$

consequently $$\kappa = 0{\cdot}98,$$

$$\kappa' = 1{\cdot}3 \quad (\text{p. } 158).$$

In this, as in all similar calculations, » a definite method of tabulating our resı found valuable in connection with our Chapter X.).

Detail.	Section in Sq. Cm.	Leakage Coefficient.	Number of Lines per Sq. Cm	f(B).	Length of Lines L in Cm.	f(B) × L.
Cast steel. Poles ..	S = 225	$\nu = 1{\cdot}28$	16,500	65	20·8	1,350
Cast steel. Yoke ...	S′m = 184	$\nu = 1$	15,800	48	77	3,700
Air-gap	St = 415	$\kappa\kappa' = 0{\cdot}98 \times 1{\cdot}3$	8,900	—	0·5	4,450
Armature	Sa = 185	—	15,700	35	18·8	660
Notches	S′a = 185	—	15,700			
						10,160

Ampere-turns per field magnet $= \frac{10}{4\pi}\, 10{,}160 = 8{,}160.$

Mean length of a field-magnet turn = 0·77 m.

Section of wire for field-magnet winding $= \dfrac{0{\cdot}77 \times 8{,}140}{50 \times 125}$ = 1 square millimetre.

Diameter of bare wire = 1·2 mm.

Diameter of insulated wire = 1·7 mm.

Number of turns per coil = 43 layers of 53 turns = 2,228.

Exciting current $= \dfrac{8{,}140}{2} : 2{,}228 = 1{\cdot}83$ amperes.

Verification.—In order that the poles should not be reversed by the armature field, it is necessary that

$$\frac{4\pi}{10} \cdot \frac{C N b}{2 p_1 D \pi} \cdot \frac{1}{2\delta} < B \text{ (see equations 26 and 27)};$$

whence
$$N < 10\, p_1 \frac{D \delta B}{C b};$$

$$\therefore N < \frac{10 \times 1 \times 20 \times 0{\cdot}25 \times 8{,}900}{36 \times 23} = 540.$$

We therefore have a coefficient of safety $= \dfrac{540}{240} = 2{\cdot}1.$

Ampere-turns of the armature (from equation 87) $= \dfrac{240 \times 36}{4 \times 1 \times 1}$ = 2,160.

$$\frac{\text{Ampere-turns of field magnets}}{\text{Ampere-turns of armature}} = \frac{8{,}140}{2{,}160} = 3{\cdot}76.$$

[illegible] *the Losses.*—(1) *Loss in the Iron.*—As the [illegible]ngly saturated as the core, we will include [illegible] calculation.

[illegible] 4,060 cubic centimetres.

If $\eta = 0{\cdot}003$, then

$\eta B^{1{\cdot}6} = 15{,}510$ (determined from Table VI. by interpolation).

Number of alternations $\omega = \dfrac{1{,}200 \times 1}{60} = 20.$

Consequently, the loss in the iron is

$$4{,}060 \times 15{,}510 \times 20 \times 10^{-7} = 126 \text{ watts.}$$

In a calculation such as this we obtain too great a result, since the armature reaction reduces the number of lines. We therefore have in the armature a number of lines corresponding to the terminal voltage of the machine, plus the ohmic loss.

(2) *Loss by Foucault Currents.*—Thickness of iron discs $= 0{\cdot}05$ cm.

According to equation (36) the loss in watts is for the iron

$$\frac{16\,(a\,\omega\,B)^2\,V}{10^{12}} = \frac{16\,(0{\cdot}5 \times 20 \times 15{,}700)^2 \times 4{,}060}{10^{12}} = 16 \text{ watts.}$$

The loss due to eddy currents in the copper and the solid iron may be taken as 48 watts.

(3) *Ohmic loss* in the wire of the armature $= 3 \times 36 =$ 108 watts.

(4) *Loss in the exciting circuit* $= 1{\cdot}83 \times 125 = 230.$

(5) *Loss due to friction* (coefficient of friction, $0{\cdot}06$).

Taking account of the traction exercised by the driving belt, the pressure may be considered to be distributed between the two bearings in somewhat the following manner:

	Z	*d*	Dissipation of Energy.
Large bearing	132 kgrm.	45 mm.	22·4 kgrm. meters
Small ,,	46 ,,	35 ,,	6·1 ,, ,,
			28·5 kgrm. meters = 280 watts.

Recapitulation.

		Watts.
(1)	Loss in the iron due to hysteresis	126
(2)	,, ,, ,, eddy currents ...	16
	,, ,, copper ,, ,, ,, ...	48
(3)	,, due to resistance of armature circuit	108
(4)	,, ,, ,, ,, exciting ,,	230
(5)	,, ,, mechanical friction	280
	Total loss	808
	Energy utilised ..	[illegible]
	Total energy	

$$\text{Efficiency} = \frac{4{,}500}{5{,}308} = 84{\cdot}5 \text{ per cent.}$$

By the use of ball bearings the frictional loss might be reduced to about a fifth of the above value, *i.e.*, to $\frac{280}{5} =$ 56 watts (about). Consequently in that case the total loss would be = 584 watts, corresponding to an efficiency of $\frac{4{,}500}{4{,}500 + 584} = 88{\cdot}5$ per cent.

Heating—Field-Magnet Circuit.—Exposed surface of an exciting coil = $(34{\cdot}5\,\pi \times 9)\ (34{\cdot}5^2 - 17^2)\frac{\pi}{4} \times 2 = 2{,}375$ sq. cm.

Loss in watts per bobbin $= \frac{230}{2} = 115$.

Heating, according to equation (45) $= 335 \times \frac{115}{2{,}375} = 17°$ C. (about).

Armature.—For a correct determination of the heating of the armature we should calculate separately the heating of the conductors in the iron carcase, and that of the external connections.

The length of a turn is equal to 0·55 m., of which 0·18 m. lies within the iron of the armature. The corresponding loss is

$$\frac{0{\cdot}18}{0{\cdot}55} \times 108 = 35 \text{ watts.}$$

$$\text{The other losses} = \underline{190} \quad ,,$$

$$\text{Total loss} = 225 \quad ,,$$

Surface = $20\,\pi \times 18 = 1{,}130$ square centimetres. We have neglected the faces at front and back of the armature, which lose little heat by radiation.

Heating, according to equation (44) $= 225\ \frac{225}{1{,}130} = 45°$ C.

Example 2.—The following calculation presents all the more interest as it refers to a dynamo constructed at the ... n Works, which obtained a first prize at the Exposition ... lle at Paris, 1889 (Figs. 100 to 102).*

... 100 and 101 all the dimensions are expressed in millimetres with ... hose referring to the length of the magnetic circuit.

The following data refer to this machine:

Terminal pressure = 600 volts.

Current strength = 330 amperes.

Speed = 500.

D = 96 cm.; l = 50 cm.

N = 400; the winding is made with a cable of 19 wires, the diameter of each being 1·3 mm.; sectional area of cable = 25 square millimetres.

Four brushes.

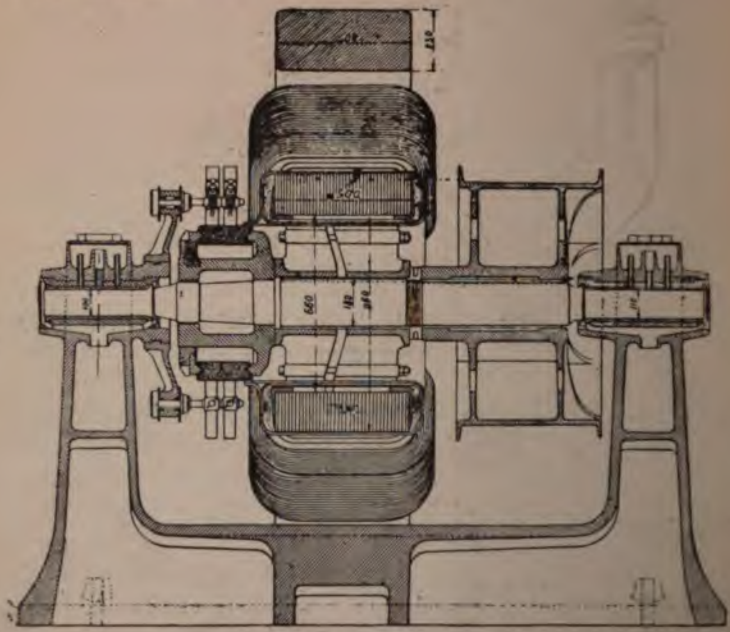


FIG. 100.

Mean length of an armature turn = 1·58 m.

" " a field-magnet turn = 2·24 m.

Fall in pressure in armature

Volts.

$$= \frac{330}{4} \times \frac{400}{4} \times \frac{1{\cdot}58}{50 \times 25} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad = 10{\cdot}4$$

Fall of pressure due to armature reaction (calculated) = 16·6

" " in field-magnet circ[illegible] = 13·0

Total ...

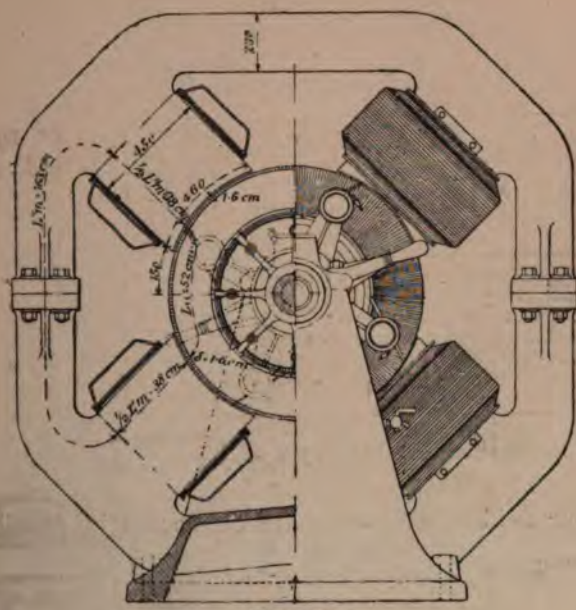


FIG. 101.

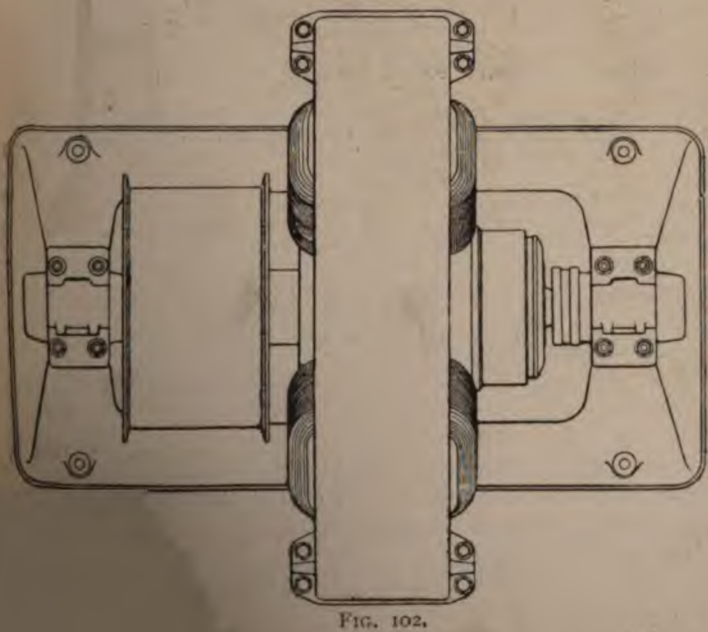


FIG. 102.

$$\phi = \frac{(600 + 40)\ 60 \times 10^8}{400 \times 500} = 19{,}200{,}000 \text{ per pole.}$$

CALCULATION OF THE FIELD MAGNETS.

Detail.	Sectional Area in Sq. Cm.	Leakage Coefficients.	Number of Lines per Sq. Cm	f(B).	Length of Lines L in Cm	f(B) × L.
Cast iron: Poles	$S'_m = 2{,}200$	$\nu = 1{\cdot}15$ (assumed)	10,000	164	76	12,500
Cast iron: External magnetic circuit	$S''_m = 2{,}300$	$\nu = 1$	8 350	89	163	14,500
Air-gap	$S_l = 2{,}300$	$\kappa = 0{\cdot}9$	7,500	—	3·2	24,000
Armature	$S_a = 1{,}300$	—	14,800	24	52	1,250
						52,250

Ampere-turns per field magnet $= \frac{10}{4\pi} \cdot 52{,}259 = 41{,}800.$

The four field-magnet coils are connected in parallel.

Current strength per field-magnet coil $= \frac{330}{4} = 82{\cdot}5$ amperes.

Number of turns per magnet coil $= \frac{41{,}800}{2} \cdot \frac{1}{82{\cdot}5} = 254.$

Sectional area of wire for a loss of 13 volts :

$$s = \frac{254 \times 82{\cdot}5 \times 2{\cdot}24}{50 \times 13} = 72{\cdot}2 \text{ square millimetres.}$$

Diameter of bare wire = 9·6 mm.
Diameter of insulated wire = 10·6 mm.

Verification.—For $\beta = 0{\cdot}6$, we should have, by equation (27),

$$N < \frac{6{\cdot}37 \times 7{,}500 \times 1{\cdot}6 \times 2 \times 2}{830 \times 0{\cdot}6} = 1{,}550.$$

The existing value of N = 400.

Ampere-turns of armature $= \frac{330 \times 400}{4 \times 2 \times 2} = 8{,}250.$

Ampere-turns of field magnets = 41,800.

$$\frac{\text{Ampere-turns of field magnets}}{\text{Ampere-turns of armature}} = \frac{41{,}800}{8{,}250} = 5 \text{ (about).}$$

Losses.—(1) Loss in the iron, due to hysteresis:
Volume of iron = 166,000 cubic centimetres.
Induction B = 14,800.
$\eta B^{1.6} = 14,100$, if $\eta = 0{\cdot}003$.

$$\text{Number of alternations } \omega = \frac{500 \times 2}{60} = 16{\cdot}7.$$

Loss: $14,100 \times 16{\cdot}7 \times 166,000 \times 10^{-7} = 3,920$ watts.

(2) Loss due to eddy currents (thickness of iron discs $= 0{\cdot}06$ cm.):

Loss in armature core

$$= \frac{16\,(0{\cdot}06 \times 16{\cdot}7 \times 14,800)^2\,166,000}{10^{12}} = 585 \text{ watts};$$

Loss in the copper (estimated) = 1,170 watts.

(3) Loss due to resistance of the armature circuit

$$= 10{\cdot}4 \times 330 = 3,440 \text{ watts.}$$

(4) Loss due to resistance of the field-magnet circuit

$$= 13 \times 330 = 4,290 \text{ watts.}$$

(5) Loss due to friction:

	Z	d	Loss.
Large bearing	2,560 kgrm.	110 mm.	4,330 watts
Small ,, ...	1,530 kgrm.	100 mm.	2,360 ,,
Total			6,690 ,,

Recapitulation.

	Watts.
(1) Hysteresis loss	3,920
(2) Loss in iron, due to Foucault currents	585
,, copper ,, ,, ,,	1,170
(3) Loss due to resistance of armature ...	3,440
(4) ,, ,, ,, exciting circuit	4,290
(5) Frictional losses	6,690
Total loss	20,095
Energy utilised = 330 × 600 =	198,000
Total energy	218,095

$$\text{Efficiency} = \frac{198,000}{218,095} = 91 \text{ per cent.}$$

CHAPTER IV.

Experimental Determination of the Permeability of Iron.

Hopkinson's original apparatus for determining the permeability of samples of iron is described in all text-books of electricity. As, however, it is not well adapted to our practical needs, a modification will here be described.

The sample of iron to be examined (which may be cast or wrought) has the form indicated in Fig. 103. To ensure exact measurements, the sections of the two magnetic circuits should be equal; moreover, the distance between the two branches should not be too small, on account of the magnetic leakage. On the middle branch are placed two bobbins—a large one, I., comprising as many turns as possible, and a small one, II., comprising two or three turns. The number of turns on the bobbin I. depends on the mean length, L, of the magnetic circuit and the strength of current employed.

Suppose, for instance, that $L = 50$ cm., and that it is required to magnetise up to 19,000 C.G.S. lines per square centimetre, the test piece being composed of cast steel; we shall require about 240 ampere-turns per centimetre length of the circuit, or altogether

$$240 \times 50 = 12{,}000 \text{ ampere-turns.}$$

If, therefore, the current strength is about 80 amperes, the bobbin I. should comprise $\frac{12{,}000}{80} \cdot 150$ turns.

The resistance R is designed to vary the strength of the exciting current, the latter being read off from the ammeter, A. G is a ballistic galvanometer, calibrated by means of a condenser, so that the quantity of electricit·· ·hrough it can be directly determined from th· e·

The number of magnetic lines of f

is determined by rapidly reversi

means of a rocking commutator; the resistance R_1 is employed to regulate the resulting throw of the galvanometer.

Let ϕ be the total number of lines of force traversing the section a; the alteration of this number due to the reversal of the exciting current is $= + \phi - (- \phi) = 2 \phi$.

The corresponding quantity of electricity discharged through the galvanometer is therefore

$$Q = \frac{2 N \phi}{R_1},$$

where N denotes the number of turns in the bobbin II. and R_1 the total resistance of the galvanometer circuit—*i.e.*, the supplementary resistance + the resistance of the bobbin II. + the resistance of the galvanometer, all measured in

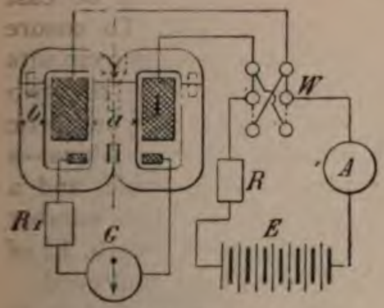


FIG. 103.

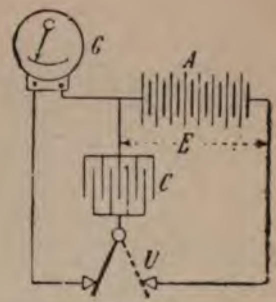


FIG. 104.

C.G.S. units. As the throws of the needle are proportional to the quantities of electricity sent through the galvanometer, we shall have, corresponding to a throw of the needle d, a quantity of electricity, Q, given by

$$Q = Q_1 \frac{d}{d_1},$$

where d_1 denotes the throw corresponding to the discharge of a quantity of electricity Q_1 from the condenser. Hence

$$\phi = Q_1 \frac{R_1}{2 N} \frac{d}{d_1} \quad . \quad . \quad . \quad . \quad . \quad . \quad (88)$$

of the Galvanometer (Fig. 104).—By the aid of key, U, the condenser, C, is first charged ·, A, and subsequently discharged through G.

Let E be the E.M.F. of the battery, in volts (in practice a single cell, of which the E.M.F. is accurately known, is alone required); K, the capacity of the condenser in microfarads. Then

$$Q_1 = E\ K\ 10^{-7} \text{ in C.G.S. units} \quad . \quad . \quad . \quad (89)$$

It should be noted that, for purposes of exact measurement, an observation of the first throw of the galvanometer needle is alone insufficient to determine d_1. The first and second oscillations, d_1' and d_1'', should be observed, when

$$d_1 = 1{\cdot}25\ d_1' - 0{\cdot}25\ d_1'' \quad . \quad . \quad . \quad . \quad (90)$$

The Author's Apparatus for Determining the Permeability of a Sample of Iron.—Methods similar to the above labour under the disadvantage that serious errors may be caused by variation of the external magnetic field; for this reason they are unsuitable for use in the workshop. Moreover, another inconvenience is introduced by the fact that *samples to be examined must possess a considerable length.* In order to obtain exact data, it is necessary to cut the sample to be examined from the actual piece of iron whose properties are required. It is only under these conditions that we may feel assured that the properties of the two pieces of iron are identical. Thus, small bars, cast by themselves, possess a structure entirely different from that of massive castings, and are harder owing to the more rapid cooling they have been subjected to. The magnetic permeability also varies in a like manner.

To evade this difficulty, the author has constructed an apparatus in which only small bars, 80 mm. in length, and with a sectional area of 500 square millimetres are required. Whilst affording sufficient accuracy for practical purposes, this apparatus may be simply and rapidly used. (Similar apparatus is used in the workshops at Oerlikon, in those of M. J. Farcot at Saint-Ouen, at the arsenal of the Austrian Lloyd's at Trieste, and by the firm of Easton, Anderson, and Co., at Erith, etc.)

The complete measurements necessary for drawing a curve up to the saturation point require only five minutes.

The construction of this apparatus depends on the principle of the magnetic balance.

According to Maxwell, the tractional force which a magnet of section S and a density of lines of force equal to B could develop is

$$Z = \frac{B^2 S}{981 \times 8\pi \times 1{,}000} \text{ kilogrammes}$$

$$= \frac{B^2 S}{25{,}000{,}000} \text{ in round numbers.} \quad . \quad (91)$$

$$\text{Hence } B = \sqrt{\frac{Z \times 8\pi \times 981{,}000}{S}} = 5{,}000\sqrt{\frac{Z}{S}} \quad . \quad . \quad (92)$$

Consequently, when Z is known, B can be calculated by means of equation (92).

TABLE FOR DETERMINING B FROM Z, USING A BAR 25·3 MM. IN DIAMETER.

B.	Z. Kilo-grammes.	B.	Z. Kilo-grammes.	B.	Z. Kilo-grammes.	B.	Z. Kilo-grammes.
500	0·05	5,500	6·05	10,500	22·0	15,500	48·0
1,000	0·20	6,000	7·20	11,000	24·2	16,000	51·2
1,500	0·45	6,500	8·45	11,500	26·4	16,500	54·5
2,000	0·80	7,000	9·80	12,000	28·8	17,000	57·8
2,500	1·25	7,500	11·22	12,500	31·3	17,500	61·3
3,000	1·80	8,000	12·80	13,000	33·8	18,000	64·9
3,500	2·45	8,500	14·50	13,500	36·4	18,500	68·5
4,000	3·20	9,000	16·20	14,000	39·2	19,000	72·3
4,500	4·05	9,500	18·00	14,500	42·0	19,500	76·0
5,000	5·00	10,000	20·00	15,000	45·0	20,000	80·0

Fig. 105 shows the elevation of this apparatus, and Fig. 106 gives a general view of it when set up ready for use.

Around the sample bar, *a*, is placed a bobbin, the arched pieces, *b* and *c*, which possess a sectional area much greater than *a*, forming with *a* a complete magnetic circuit. The arched piece *b* rests on two knife-edges, *d*, so that the surfaces *e e* remain always at the same distance apart, whatever may be the position of the apparatus. The surface, *f*, as well as the ends of the sample bar, must be made exactly plane. In order to facilitate working, the bobbin is supported on a carriage, so as to permit of its quick displacement toward one side. The arched piece *g* serves to maintain equilibrium whilst the lever, *k*, is adjusted.

Calibration of the Apparatus.—The weight, *i*, is first adjusted so as to obtain equilibrium, its position being marked on the

lever, k, with a vertical scratch. Suspending successively the weights Z (given in the preceding table) from the arched

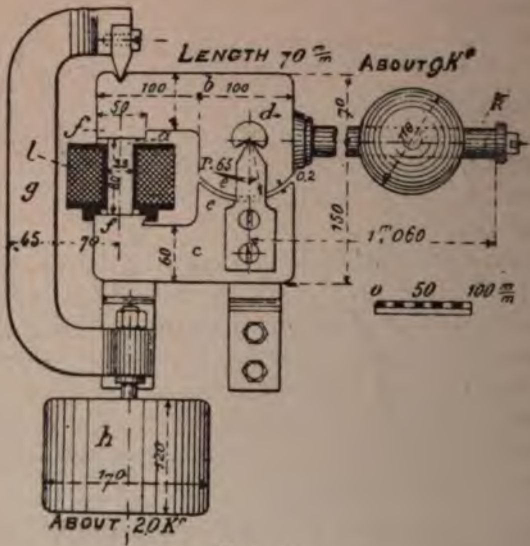


FIG. 105.

piece g, and moving the weight, i, till equilibrium is in each case re-obtained, the lever, k, can be calibrated so as to give direct readings for Z.

FIG. 106.

The last mark indicates the values of B when the arched piece g is raised. In this latter case, the weight of g and h

must be added to Z. By this means we avoid overweighting the knife-edges, as well as the necessity of having a very long lever.

It follows that during the time that a measurement is being made, the apparatus should be placed with the lever horizontal; accurate results can be obtained only when this precaution is taken.

When a long series of measurements are to be made it is well to graduate the ammeter in terms of the number of ampere-turns per unit length of the test piece (= one-eighth of the total ampere-turns).

Let us suppose that it is necessary to examine a given test piece; the weight, i, is placed at a point corresponding to a given density of lines of force, the arched piece g and h being suspended, and the exciting current is reduced, by the aid of a rheostat, until the armature of the electromagnet is just detached. One could equally well maintain the exciting current constant, and alter the position of the weight, i, till the armature is detached.

Correction of the Results of Tests.—When it is required to examine samples for saturation values of B, the magnetic resistances of the yoke and the air-gap, *e e*, may be neglected. On the other hand, for smaller values of B, a small correction must be applied. As a matter of fact, with the dimensions given in the diagram, in order to overcome the magnetic resistance of the yoke and the air-gap, *e e*, together with the air-gaps at the ends of the sample bar, an extra number of ampere-turns equal to

$$\frac{1{\cdot}8}{1{,}000}\,\mathrm{B} + \frac{0{\cdot}9}{1{,}000}\,\mathrm{B}$$

must be added. With a sample bar 1 cm. in length, this will become

$$\frac{0{\cdot}22\ \mathrm{B}}{1{,}000} + \frac{0{\cdot}116\ \mathrm{B}}{1{,}000}.$$

In the first term account is taken of the magnetic resistance of the iron; in the second, that of the air-gaps.

As already stated, the measurements thus obtained are sufficiently accurate for all practical purposes. Thus, even if

the correction factor is taken *twice too small* or *too great*, the maximum error possibly introduced with a wrought-iron test piece magnetised to 10,000 lines of force will be at most 20 per cent.; in cases where the test piece is saturated, this error completely disappears.

CHAPTER V.

SOLUTION OF SOME PRACTICAL PROBLEMS BY GRAPHIC METHODS.

Graphic methods have seldom been employed for the purpose of effecting systematic calculations in connection with continuous-current dynamos, a fact which is the less comprehensible when it is remembered that no known method can entirely dispense with the use of similar principles.

The reason of this restricted employment of graphic methods must doubtless be sought in the prevailing ignorance of the benefits which would spring from their use. To our knowledge, M. Picou, in his work on "Dynamo-Electric Machines," was the first to present such methods in a form capable of being practically used.

For this reason we will, in the following pages, pass in review some of the most important problems in connection with continuous-current dynamos, so as to point out the simplicity of their solutions by graphic methods.

A. Tracing the Characteristic Curve.

To solve the problems which ordinarily arise in practice it is generally sufficient to know two or three points on the characteristic curve, which may then be traced in the usual manner, availing ourselves of Hopkinson's curves. But it happens sometimes that a greater number of points are required, when the method becomes much more laborious. When it is not necessary to proceed with great accuracy, we may employ the following method, which leads rapidly to the desired end.

In the most simple form, the formula of Hopkinson may be written :

$$C_m N_m = L_m f(B_m) + L_a f(B_a) + L_l f(B_l).$$

In this formula, B_m, B_a, and B_l denote the density of the lines of force in the field magnets, the armature and the air-gap respectively; L_m, L_a, L_l denote the mean length of path of these lines; and C_m N_m the total number of ampere-turns of the magnetic circuit. The values of f (B_m) and f (B_a) may be taken from the well-known magnetisation curves; to obtain f (B_l) we may use the formula

$$f(B_l) = 0{\cdot}8\,\kappa\,\kappa'\,L_l\,B_l,$$

which represents the equation of a straight line. The total number of ampere-turns is therefore given by the sum of the abscissæ of two curves and a straight line. The complication thus introduced is more apparent than real; we may as a general rule neglect the values of the curve f (B_a) in comparison with the greater values of the other two terms; or better, we may assume that f (B_a) is for values occurring practically proportional to B_a. The graphical method to be employed is then as follows:

In the case of a dynamo possessing field magnets with wrought or cast iron cores, use may be made of Hopkinson's curves; a great number of different curves may be obtained, as the magnetic behaviour of different specimens of iron vary very greatly. Suppose that the ordinates of such a curve denote the number of lines of force per square centimetre, and that the abscissæ denote the corresponding number of ampere-turns per unit length of the lines of force. By multiplying the abscissæ by L_m we obtain the number of ampere-turns necessary to overcome the magnetic resistance of the field magnets. This may be done most simply by dividing anew the axis of abscissæ in such a manner that the new divisions are each L_m times as great as the original ones.

The ampere-turns necessary to overcome the magnetic resistance of the air-gaps and the armature can, as previously stated, be considered as approximately proportional to the induction.

As the density of the lines of force in the cores of the field magnets serves as the basis for the saturation curves, we may calculate once for all the values of B_a and B_l corresponding to any sufficiently high value of B_m. Thus

$$B_a = B_m \frac{S_m}{S_a}.$$

$$B_l = B_m \frac{S_m}{S_l}.$$

In these formulæ we denote by S_m the sectional area of the field-magnet core, measured in square centimetres; S_a, the sectional area of the armature; S_l, the sectional area of the air-gap.

The necessary ampere-turns are given by

$$C_m\ N_m = L_a\ 0{\cdot}0005\ \frac{B_m\ S_m}{S_a} + L_l\ 0{\cdot}8\ \frac{B_m\ S_m}{S_l}\ \kappa\,\kappa',$$

$$\text{or,} \quad C_m\ N_m = B_m\,S_m\left(0{\cdot}0005\,\frac{L_a}{S_a} = 0{\cdot}8\ \frac{L_l}{S_l}\ \kappa\,\kappa'\right).$$

The number thus obtained is the abscissa of a point, A, whose ordinate is B_m (Fig. 107). This point may be joined by a straight line to the origin of co-ordinates, O. Adding successively, by means of a pair of dividers, the abscissæ of the straight line, O A, to the corresponding abscissæ of the saturation curve, O B, the new curve, O C, is obtained. This will be the characteristic curve required. It must be noticed that up to the present no account has been taken of the leakage of the lines of force from the field magnets. To make allowance for this we adopt a new unit for the ordinates of the saturation curve, which must be ν times as great as the first unit (ν being the coefficient of leakage). The degree of saturation which we can obtain from a given number of ampere-turns is thus slightly smaller than the value originally obtained. The ampere-turns determined for the air-gap and the armature must naturally be taken proportional to these new ordinates.

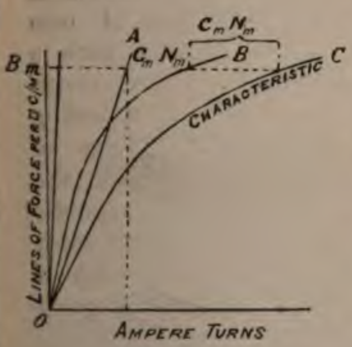


Fig. 107.

When it is required to draw a characteristic curve expressing the relation between the ampere-turns and the E.M.F., another

transformation of the ordinates must be effected. We may spare ourselves the double trouble by multiplying the number obtained in the last operation by ν, and then taking the unit for the ordinates of the curve ν times greater, *i.e.*, by dividing all the ordinates by ν.

Example.—It is required to trace the characteristic curve of a bipolar dynamo generating 120 amperes at a pressure of 120 volts, revolving at the rate of 1,470 revolutions per minute. The cores of the field magnets are of cast iron, and their sections are uniform.

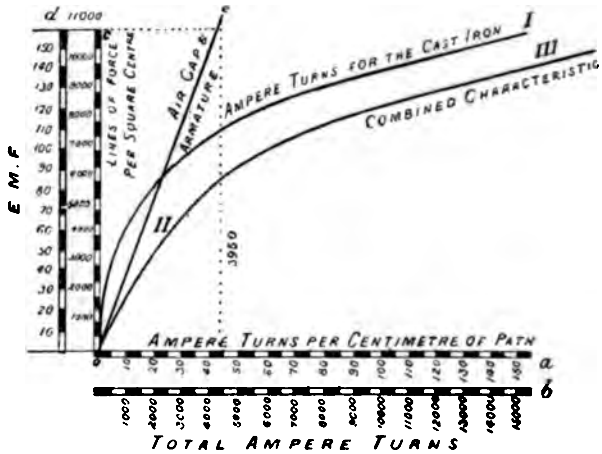


FIG. 108.

The dimensions of the dynamo are as follows:

$$L_m = 100; \qquad S_m = 390;$$
$$L_a = 37; \qquad S_a = 220;$$
$$L_l = 0{\cdot}6; \qquad S_l = 631.$$

Number of conductors on armature = 180.

Coefficient of leakage $\nu = 1{\cdot}2$; $\kappa\,\kappa' = 0{\cdot}9$.

For the purpose of this calculation we will employ the magnetisation curve for cast iron, given in Fig. 108, after having multiplied all the abscissæ by $L_m = 100$.

We arrive in this manner at the scale marked b, in which the abscissæ represent the total ampere-turns necessary to overcome the magnetic resistance of the field magnets, the magnetic leakage being neglected. To take account of the leakage, all the ordinates must be subsequently divided by ν.

To determine the ampere-turns necessary to overcome the magnetic resistance to the passage of lines of force between the pole-pieces and the armature, and in the iron of the armature itself, we must make use of the equation previously given, substituting for B_m a number as great as possible—for example, 11,000.

$$C_m N_m = 11{,}000 \times 390 \left(0{\cdot}0005 \frac{37}{220} + 0{\cdot}8 \frac{0{\cdot}6}{631} 0{\cdot}9\right)$$
$$= 3{,}290 \text{ (approximately).}$$

This number must now be multiplied by $\nu = 1{\cdot}2$.

$$1{\cdot}2 \times 3{,}290 = 3{,}950.$$

We now obtain the point *e*, of which the co-ordinates are 3,950 and 11,000; this point is joined to the origin, O, by a straight line, O *e*. The abscissæ of the various points on the straight line, O *e*, are now added, by means of a pair of dividers, on to the corresponding abscissæ of the Curve I. We thus obtain the Curve III., which may be taken as the required characteristic curve when the scale of ordinates has been divided anew so as to read directly in volts.

To obtain the voltage corresponding to any given ordinate of the original scale, it is only necessary to multiply the number in question by

$$\frac{1}{\nu} \; \frac{1{,}470 \times 180 \times 390}{60 \times 10^8} = 0{\cdot}0143.$$

This multiplication gives rise to the scale *d*, the magnetic leakage being allowed for.

The graphic method which has been explained is only applicable to the determination of the characteristic curve of a dynamo when the armature consists entirely of cast or wrought iron, and when its section is uniform for the whole of the paths of the lines of force.

B. Determination of the Drop in Voltage of a Shunt-Wound Dynamo.

M. Picou has given a very elegant method for the determination of the fall of pressure in a shunt-wound dynamo. Fig. 109 represents the characteristic curve of a dynamo of this class, expressed in terms of current strength

and E.M.F. Let E be the voltage at which the machine works when self-excited on open circuit. Then

$$\frac{E}{C_m} = \tan \alpha = r.$$

(r being the resistance of the field-magnet circuit).

Hence $$C_m = \frac{E}{r}.$$

Connecting E with O, the current strength, for any voltage whatever at the brushes, can be immediately found by determining the abscissa of the point on the straight line, O E, which corresponds to the particular voltage. It is now necessary to determine by how much E is lowered when a current, C, is flowing through the armature, the resistance of the latter being R. In that case (Fig. 109) $e = C\ (R + R_1)$.

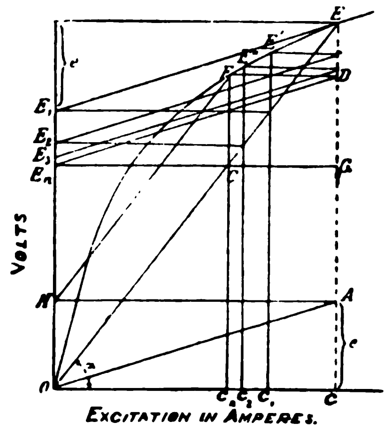


FIG. 109.

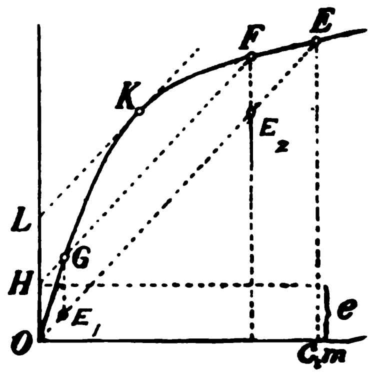


FIG. 110.

In this equation C R_1 denotes the probable fall of potential produced by the reaction of the armature taken approximately; a small error in this quantity will not influence the final result. When no information as to the value of this quantity is possessed, we may take it equal to C R or to 2 C R.

The point A being connected by a straight line to the origin, O, a straight line, E E_1, is drawn from E parallel to O A.

E_1 corresponds to the point to which the impressed E.M.F., E, is reduced owing solely to the resistance of the armature.

A secondary effect is, however, produced. The strength of the exciting current is, in fact, modified at the same time. Instead of the value C_m, we have only $(C_m)_1 = \frac{E_1}{r}$. This can be obtained by drawing a horizontal line from E_1, and from its intersection with the line O E dropping a vertical line.

But the new current strength, $(C_m)_1$, produces a voltage E'; treating this new value in a manner similar to that previously described, we arrive at E_2, as a second approximation to voltage.

Proceeding in this manner, we finally obtain the closed figure

$$E_n \; D \; F \; C,$$

and it is easy to see that

$$F \, C = D \, G = e.$$

This leads to a much more simple solution of the problem. In fact, if a straight line, F H, is drawn parallel to O E, then it is easy to see that H O = e.

One can, therefore, proceed as indicated in Fig. 110. O H is made equal to e, and from H is drawn a straight line, H F, parallel to O E. From F, the intersection of this line with the curve O E, a vertical line is drawn; the point C, where this line intersects O E, will give the required terminal pressure of the dynamo.

The curve shows equally well that the drop in voltage is the more considerable as the degree of saturation is diminished.

The above method possesses more importance from a theoretical than from a practical point of view, since it is impossible to predetermine, with even approximate accuracy, the value of C R_1. But it, nevertheless, leads to some important conclusions respecting the working of shunt-wound dynamos. Indeed, Fig. 110 shows that the straight line, H F, cuts the characteristic curve in two points, G and F, corresponding to the terminal pressures, E_1 and E_2 respectively.

As a consequence, shunt-wound dynamos exhibit the peculiarity that, with a given strength of current, they can work with two different terminal pressures. The maximum current corresponds to the point of intersection, K, of the

tangent L K, to the characteristic curve. The manner in which the current and the voltage influence each other is shown in Fig. 111, which can be obtained without difficulty from Fig. 110. Theoretically, the curve should return to the origin of co-ordinates, but, owing to permanent magnetisation, the curve actually obtained follows the path indicated by the continuous curve.

From that which has already been proved, we may draw the following conclusion: As the external resistance of a shunt-wound machine is diminished, the armature current increases till a maximum value is reached, after which it decreases. With a well-designed dynamo it will probably be found impossible to obtain the complete form of the above

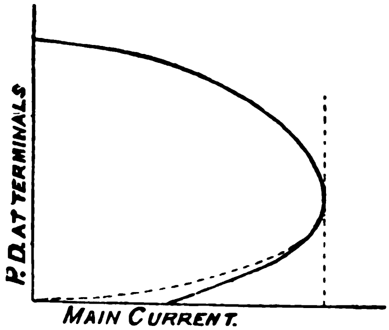


FIG. 111.

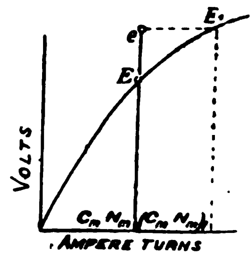


FIG. 112.

curve, owing to the risk of burning up the machine. On the other hand, by diminishing the resistance it is possible to determine a certain number of points on the straight part of the curve. The conditions might even be produced accidentally if during the test of an over-loaded machine a large resistance were suddenly removed from the external circuit.

It is, indeed, by reason of this property that shunt-wound dynamos possess the advantage over other forms of machines that, even when suddenly short-circuited, the current produced cannot attain to a dangerous magnitude.

C. Determinations with Compound-Wound Machines.

The solution of this problem is extremely simple. Let Fig. 112 represent the characteristic curve of the dynamo

of which it is required to determine the nature of the winding. The co-ordinates represent the ampere-turns of the exciting current and the E.M.F. produced. Moreover, let E represent the terminal voltage which it is required to maintain constant.

From the point E on the characteristic curve drop a perpendicular on the axis of abscissæ; the abscissa ($C_m\ N_m$) of this point gives the number of ampere-turns necessary when the machine is working on open circuit; or, in other terms, the ampere-turns in the shunt winding. In that case, E is not only the terminal voltage but also the induced E.M.F.

We shall consider first a compound dynamo connected as shown in Fig. 57.

Let, then, e be the fall of potential in the armature and series winding added to the probable fall in voltage due to armature reaction; we must produce in the dynamo, in order that E may be constant, an E.M.F., or an internal voltage equal to E_1, which is equal to $E + e$. But the ampere-turns necessary to produce this effect are, after Fig. 100, given by $(C_m\ N_m)_1$; the ampere-turns of the compound winding are therefore equal to $(C_m\ N_m)_1 - (C_m\ N_m)$.

If the shunt is connected across the armature, as shown in Fig. 58, and E_2 be the pressure at terminals of the shunt at full load, then the ampere-turns of series winding will be

$$(C_m\ N_m)_1 - \frac{E_2}{E} C_m\ N_m .$$

D. Determination of the Regulating Resistance for a Shunt-Wound Dynamo.

Such a regulating apparatus may be employed for several different purposes:

(*a*) To realise a constant terminal voltage when the load varies, the rate of revolution remaining constant.

(*b*) To maintain the voltage at the brushes constant when the speed varies.

(*c*) To compensate simultaneously for variations of load and speed.

(*d*) To obtain any required variation in the voltage.

Problem a.—Regulation of a Shunt-Wound Dynamo when the Load varies.

In Fig. 113 let

E = the voltage at the brushes;
r_m = the resistance of the field-magnet circuit;
r_w = the resistance of the regulating rheostat;
N_m = the number of turns of wire for the magnetic circuit.

We will suppose that the dynamo is driven at a constant speed, and that on full load the whole of the adjustable resistance is removed from the circuit.

It remains, then, to determine what must be the value of the resistance which must be added to the field-magnet circuit in order that the voltages on open circuit and full load may be equal. We must first determine the strength of the exciting current when the machine is on open circuit $(C_m)_1$, and for full load $(C_m)_2$, using the method which we

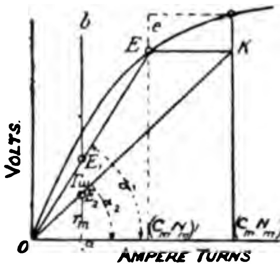


FIG. 113.

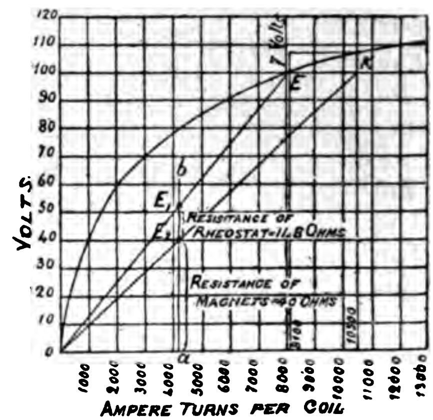


FIG. 114.

have already explained (p. 196) in determining the ampere-turns for E and E + e. We then have

$$(C_m)_1 = \frac{(C_m N_m)_1}{N_m};$$

$$(C_m)_2 = \frac{(C_m N_m)_2}{N_m}.$$

Moreover,

$$r_m + r_w = \frac{E}{(C_m)_1} = \frac{N_m E}{(C_m N_m)_1} = \tan \alpha_1;$$

$$r_m = \frac{E}{(C_m)_2} = \frac{N_m E}{(C_m N_m)_2} = \tan \alpha_2.$$

But the values of r_m and $r_m + r_w$ may be obtained directly. It is only necessary to draw, at a distance, N_m, from the axis of ordinates, a line *a b* parallel to that axis. This line will cut O E and K O in points E_1 and E_2, and we shall have the following relations:

$$\tan \alpha_1 = \frac{N_m E_1}{N_m} = E_1 = r_m + r_w;$$

$$\tan \alpha_2 = \frac{N_m E_2}{N_m} = E_2 = r_m.$$

The lengths of E_1 and E_2 give, therefore, direct values for the magnitudes of the required resistances. Moreover,

$$E_1 - E_2 = r_w;$$

i.e., the difference of the pressures gives a measure of the resistance to be added.

Example.—It is required to provide a shunt-wound dynamo of 100 volts and 50 amperes, possessing the magnetic properties given in Fig. 114, with an adjustable resistance, to be used to maintain the voltage constant from open circuit to full load.

The drop in voltage for 50 amperes = 7 volts.

The characteristic shows that, on open circuit, a number of ampere-turns, $(C_m N_m)_1$, are necessary where

$$(C_m N_m)_1 = 8{,}100;$$

and on full load

$$(C_m N_m)_2 = 10{,}500.$$

Assuming a waste of 5 per cent. of the total current in the windings, the field magnets must then be furnished with

$$\frac{10{,}500}{0 \cdot 05 \times 50} = 4{,}200 \text{ turns.}$$

The calculation now gives

$$r_m + r_w = \frac{N_m E}{(C_m N_m)_1} = \frac{4{,}200 \times 100}{8{,}100} = 51 \cdot 8\ \omega;$$

$$r_m = \frac{N_m E}{(C_m N_m)_2} = \frac{4{,}200 \times 100}{10{,}500} = 40 \cdot 0\ \omega;$$

$$- 40 \cdot 0 = 11 \cdot 8\ \omega.$$

We could have determined these numbers with a sufficient degree of accuracy by drawing a line, *a b*, parallel to the axis of ordinates, and at distance from it equal to

$$N_m = 4{,}200$$

and obtaining the points E_1 and E_2.

When the dynamo possesses two field-magnet bobbins of which the turns are 0·52 m. in length, the wire of the field magnets should have a section of

$$\frac{2\ N_m\ L}{50\ r_m} = \frac{2 \times 4{,}200 \times 0{\cdot}52}{50 \times 40} = 2{\cdot}18 \text{ square millimetres.}$$

Problem b.—To Regulate a Shunt-Wound Dynamo for a Constant Voltage, the Speed being variable.

For simplicity, we will suppose, to start with, that the dynamo is run on open circuit, or, what is the same thing, that the current is so small that the fall in pressure may be neglected.

Let, then, n represent the normal number of revolutions;
n_1 the abnormal number of revolutions, maximum or minimum;

Let $$\frac{n_1}{n} = \gamma.$$

According as the speed of rotation increases or diminishes, γ will be $>$ or $<$ 1.

The problem may be solved in a general manner including both cases.

To obtain the characteristic of the dynamo corresponding to any abnormal number of revolutions, it is only necessary to multiply the ordinates of the primitive characteristic Curve I. by γ (Figs. 115 and 116). The Curve II. (Fig. 115) corresponds to the case where the number of revolutions per minute is increased; the Curve II. (Fig. 116) refers to the case where the number of revolutions per minute is diminished.

Let E be the voltage of the dynamo when it excites itself, and when the number of revolutions is normal ($= n$). Joining E to O by means of a straight line prolonged beyond E, the point of intersection, E_n, of that line with the Curve II. corresponds to the voltage of the dynamo increased to n_1 revolutions. We will

solely to the case where the speed of rotation is increased; a similar method may be used when the speed of rotation is diminished.

We may follow the succession of the phenomena which occur somewhat after the following manner: At the first moment the voltage E increases with the number of revolutions, and reaches the value E_1; but as may be plainly seen, the exciting current increases equally, due to the increased voltage between the brushes. The magnetising force consequently increases from $C_m N_m$ to $(C_m N_m)_1$; but the voltage E_2 corresponds to this magnetising force; consequently $(C_m N_m)_1$ is increased to $(C_m N_m)_2$, and so on.

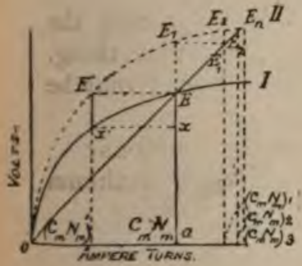


FIG. 115.

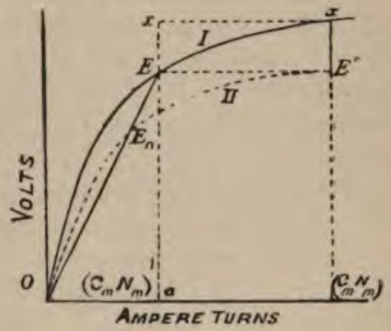


FIG. 116.

It is evident that equilibrium will be attained at the point of intersection of the straight line, O E, with the Curve II.

But these phenomena are of little importance as far as the solution of the present problem is concerned, since it is required to maintain the voltage of the dynamo constant. For this purpose we will find from the Curve II. the number of ampere-turns which produce the voltage E. That number is $(C_m N_m)'$.

It can easily be seen that to solve the proposed problem it is useless to have recourse to the auxiliary Curve II. Since, indeed, the ampere-turns found from the Curve II. for the voltage $E' = E_1$ are identical with those of which we have need to produce the voltage

$$x' = \frac{E'}{\gamma} = \frac{E}{\gamma},$$

the number of revolutions being normal, it is only necessary to

mark on the vertical a E the point x at a distance $\frac{E}{\gamma}$ from a, and to draw the parallel $x\,x'$. The abscissa of the point of intersection, x', of this line with the characteristic curve gives the required number of ampere-turns.

$$\text{For } \gamma > 1, \text{ we have } (C_m\ N_m)' < C_m\ N_m$$

$$\text{For } \gamma < 1, \text{ we have } (C_m\ N_m)' > C_m\ N_m$$

In the first case we must diminish the excitation by introducing a resistance into the field-magnet circuit; in the second case we must increase the current strength by reducing the resistance in the shunt circuit. In order to fulfil these conditions it is necessary to design the resistance of the field-magnet windings in such a manner that a certain part of the regulating resistance, r_w, is included in the field-magnet circuit when the machine is working at its normal speed. The resistances required may be calculated in the following manner:

For $n_1 > n$ we have

$$r_m + r_w = \frac{E}{\frac{(C_m\,N_m)'}{N_m}}, \quad r_m = \frac{E}{\frac{C_m\ N_m}{N_m}};$$

hence,
$$r_w = N_m\ E\left(\frac{1}{(C_m N_m)'} - \frac{1}{C_m\ N_m}\right).$$

For $n_1 < n$ we have

$$r_m + r_w = \frac{E}{\frac{C_m\ N_m}{N_m}}, \quad r_m = \frac{E}{\frac{(C_m N_m)'}{N_m}};$$

hence,
$$r_w = N_m\ E\left(\frac{1}{C_m\ N_m} - \frac{1}{(C_m N_m)'}\right).$$

If a parallel be drawn, as in the preceding example, at a distance, N_m, from the axis of ordinates, these resistances may be read off directly.

Example.—Suppose that it is required to regulate a dynamo (Fig. 117) of 125 amperes and 120 volts on open circuit, for which the number of revolutions varies by 9 per cent. below and 10 per cent. above the normal number. What should be the resistance of the field magnets and of the adjustable

;tance for the exciting circuit, assuming a field loss of
per cent. when the rate of revolution is normal.

field loss of 3·2 per cent. corresponds to 4 amperes in the
ting circuit.

he number of turns of wire must therefore be

$$\frac{20{,}000}{4} = 5{,}000 \text{ (see Fig. 117).}$$

$\gamma = 0{\cdot}91$ we have $x_1 = \dfrac{120}{\gamma} = 132$, and $C_m\ N_m = 27{,}600$.

$\gamma = 1{\cdot}1$ we have $x_2 = \dfrac{120}{\gamma} = 109$, and $C_m\ N_m = 15{,}400$.

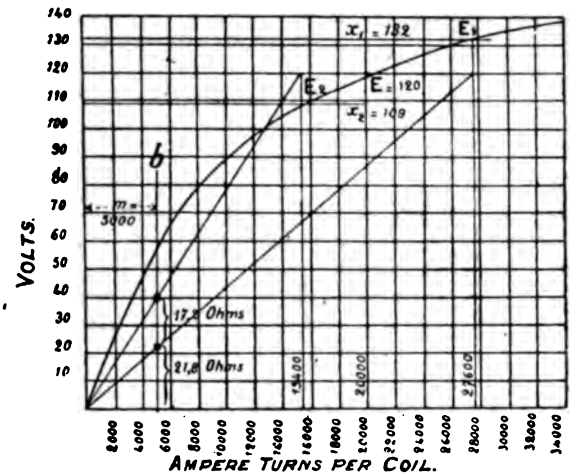


FIG. 117.

$$r_m + r_w = \frac{5{,}000 \times 120}{15{,}400} = 39\ \omega;$$

$$r_m = \frac{5{,}000 \times 120}{27{,}600} = 21{\cdot}8\ \omega;$$

$$r_w = 39 - 21{\cdot}8 = 17{\cdot}2\ \omega.$$

e also the graphic determination of r_m and r_w (Fig. 117).

blem c.—Compensation for Variations in both Load and Speed.

The regulating resistance will evidently fulfil all that is
ired of it if it is capable of equalising the voltage at

full load and minimum speed with that on open circuit at maximum speed. We have already considered the first of these two cases in obtaining the solution of problem B.

In order to solve the second problem we may again use Curve I. (Fig. 116) for the case of open circuit and normal speed, and the Curve II. for the lesser speed n_1, using the relation

$$\frac{n_1}{n} = \gamma.$$

If E be the voltage at the brushes, which we wish to maintain constant, and for which we have need of $(C_m\ N_m)_1$ ampere-turns when the speed is normal and the machine is working on open circuit (Fig. 118), we must find the magnetising force for the reduced speed by obtaining from the Curve II. the abscissa $(C_m\ N_m)_2$ for

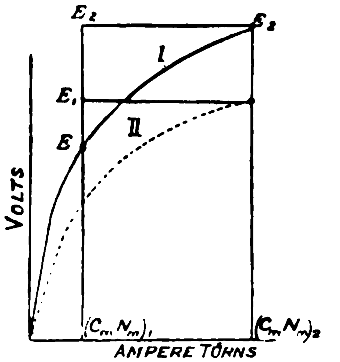


FIG. 118.

$$E_1 = E + e.$$

It can further be seen that for this purpose the Curve II. is unnecessary, since $(C_m\ N_m)_2$ is the abscissa of E_1 on the curve of reduced speed, as well as of E_2 on the curve corresponding to the normal speed. It follows that the problem may be simplified in the following manner:

We will add to E the drop in voltage e, and divide the sum by γ. We will then seek on the primitive characteristic curve of the dynamo for the number of ampere-turns corresponding to the value E_2. For the calculation of the section of the wire used we may use the well-known equations (62) and (64).

Let then N_m be the number of turns in the bobbin;

N_1, the number of bobbins grouped in series;

L, the length of a single turn of the field-magnet circuit in metres. Then (equation 62)

$$\ldots N_1 L$$

when $$N_m = \frac{(C_m N_m)_2}{C''_m}.$$

This is, then, the section of the wire of the field-magnet windings which will give a voltage at the brushes equal to E, with a minimum speed n_1 and a maximum current strength in the armature, the adjustable resistance being entirely removed from the circuit.

On open circuit, when the speed is increased we will have need of $(C_m N_m)'$ ampere-turns (see Fig. 115). In that case a resistance r must be added to the field-magnet circuit. Then

$$r_w = \frac{E N_m}{(C_m N_m)'} - r_m, \text{ and } r_m = \frac{E N_m}{(C_m N_m)_2},$$

whence $$r_w = E N_m \left(\frac{1}{(C_m N_m)'} - \frac{1}{(C_m N_m)_2}\right),$$

which is a formula we have already considered.

Example.—It is required to arrange an adjustable resistance and the winding of a dynamo, of which the pressure at the brushes is 60 volts, the current being 30 amperes, in such a manner that the voltage at the brushes may be maintained constant for any load, the speed varying by 10 per cent. above or below the normal speed. The fall of voltage is supposed equal to 3 volts. The characteristic curve for this dynamo is represented by Fig. 119.

(*a*) Determination of the ampere-turns for minimum speed and maximum current strength:

$$E_1 = E + e = 60 + 3 = 63 \text{ volts};$$

$$\gamma = \frac{n_1}{n} = 0{\cdot}9.$$

$$E_2 = \frac{E_1}{\gamma} = \frac{63}{0{\cdot}9} = 70 \text{ volts}.$$

$$(C_m N_m)_2 = 5{,}500.$$

(*b*) Determination of the ampere-turns for maximum speed when the dynamo works on open circuit:

$$\gamma = \frac{n_1}{n} = 1{\cdot}1.$$

$$E_3 = \frac{E}{\gamma} = \frac{60}{1{\cdot}1} = 54{\cdot}5 \text{ volts}.$$

$$(C_m N_m)' = 2{,}500.$$

(*c*) Calculation of the section of the wire used in winding the field magnets, and of the number of turns, for $N_1 = 2$, $L = 0{\cdot}5$ m:

$$s = \frac{5{,}500 \times 2 \times 0{\cdot}5}{60 \times 50} = 1{\cdot}83 \text{ square millimetres.}$$

Assuming a field loss of 7 per cent. = 2·1 amperes, we obtain

$$\frac{5{,}500}{2{\cdot}1} = 2{,}620 \text{ turns per bobbin.}$$

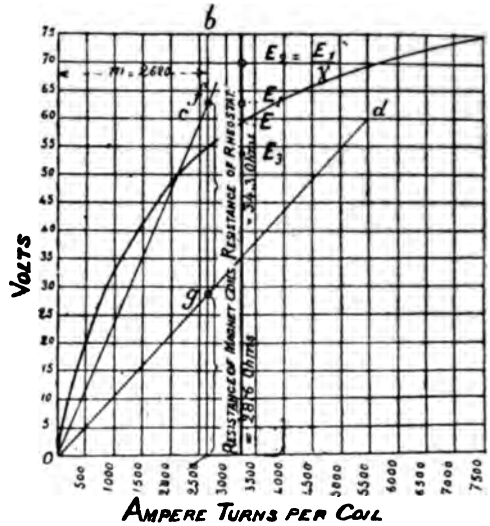


FIG. 119.

(*d*) Determination of the resistance to be added: Connect O with the intersections, *c* and *d*, of the verticals drawn through the abscissæ 2,500 and 5,500, with a line drawn through E parallel to the axis of abscissæ. Further, draw a line parallel to the axis of ordinates at a distance $N_m = 2{,}620$ from it. We thus obtain the points of intersection, *f* and *g*, and the length *a g* will be equal to the required resistance of the field-magnet circuit, the length *f g* will be equal to the resistance to be added to that circuit. This result may be verified as follows: We have

$$r_m + r_w = \frac{N_m \, E}{(C_m \, N_m)'} = \frac{2{,}620 \times 60}{2{,}500} = 62{\cdot}9 \, \omega.$$

$$r_m = \frac{E}{(C_m)_1} = \frac{60}{2 \cdot 1} = 28 \cdot 6\ \omega.$$

$$r_w = 62 \cdot 9 - 28 \cdot 6 = 34 \cdot 3.$$

Problem d.—To Alter the Terminal Voltage.

Suppose that the voltage must be regulated between a minimum E_1 and a maximum E_2, independently of the momentary value of the armature current. When the adjustable resistance is removed from the circuit, the terminal voltage will be equal to E_2. When the adjustable resistance is included in the field-magnet circuit, the terminal voltage should be E_1.

Let us suppose that the characteristic curve gives, corresponding to E_1, a magnetising force of $(C_m\ N_m)_1$ ampere-turns, and corresponding to E_2 volts at the brushes, or rather, to an internal voltage of $E_2 + e$, a magnetising force $= (C_m\ N_m)_2$. We shall then find, for the section of the wire used for winding the electromagnets,

$$s = \frac{(C_m\ N_m)_2\ N_1\ L}{E_2\ 50}.$$

Moreover,

$$(C_m\ N_m)_2 = \frac{N_m\ E_2}{r_m};$$

$$(C_m\ N_m)_1 = \frac{N_m\ E_1}{r_m + r_w};$$

whence

$$r_w = N_m \left(\frac{E_1}{(C_m\ N_m)_1} - \frac{E_2}{(C_m\ N_m)_2} \right).$$

We could directly obtain a value of this resistance, as already shown, by drawing a parallel to the axis of ordinates at a distance, N_m, from it (Fig. 120).

E. Characteristic for Variable Speed.

The solution of this problem, which consists in finding the characteristic curve in the case where the speed varies, may be deduced from the method used in problem *b* (p. 200).

The Curve I. (Fig. 121) represents the characteristic of the dynamo when the speed is normal and equal to *n*. The point E gives the voltage with which the machine works on open

circuit. Multiplying the ordinates of that curve by $\gamma = \frac{n_1}{n}$ (γ may be > or < 1) we obtain the Curve II., and the point of intersection E_1 of the straight line O E with the Curve II. will give the resulting voltage when the machine makes n_1 revolutions per minute without an auxiliary resistance in the field-magnet circuit.

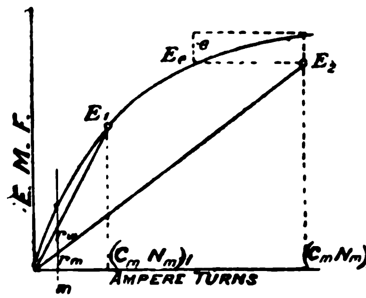


FIG. 120.

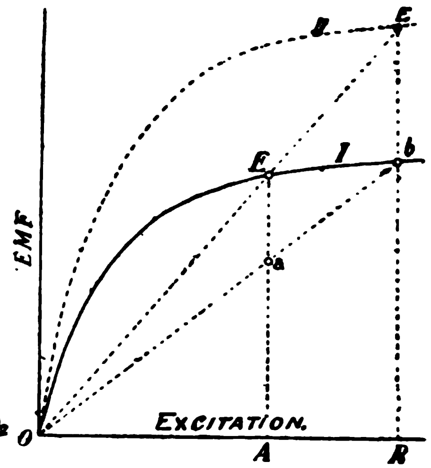


FIG. 121.

Dropping, from E_1, the vertical E_1 B, we shall have

$$\frac{E\,A}{a\;A} = \frac{E_1\,B}{b\,B} = \gamma = \frac{n_1}{n};$$

or,

$$\frac{a\;A}{E\,A} = \frac{n}{n_1};$$

$$E_1 = b\;B\,\frac{n_1}{n}.$$

These two equations lead to the following simple solution of the example in question (see Fig. 122): Take on the vertical E A a sufficiently great number of points, a_1, a_2, a_3, etc., of which the respective ordinates are—

$$a_1 = \frac{n}{n_1}\,E\,A;$$

$$a_2 = \frac{n}{n_2} \text{ E A};$$

$$a_3 = \frac{n}{n_3} \text{ E A, etc., etc.,}$$

Join this point with O, the origin of co-ordinates, and mark the points of intersection of the straight lines with

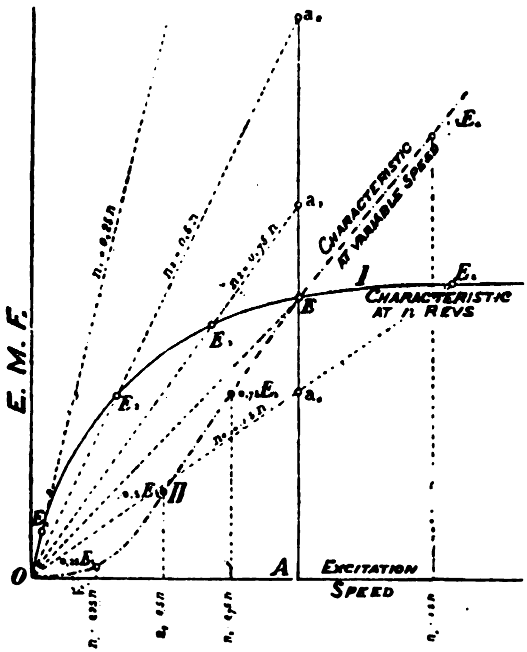


FIG. 122.

the characteristic curve. These points are E_1, E_2, E_3, etc. The voltages sought are therefore, for n_1, n_2, n_3, etc., respectively equal to

$$\text{E}\frac{n_1}{n}, \text{ E}\frac{n_2}{n}, \text{ E}\frac{n_3}{n}.$$

F. Transmission of Energy by Means of Two Series-Wound Dynamos.

The conditions which must be complied with in this case have already been enumerated (pp. 81-86).

CHAPTER VI.

THE RELATION BETWEEN LEAD AND SPARKING IN CONTINUOUS-CURRENT MACHINES.

The electrical output of a continuous-current machine is, as we have seen, limited by the heating of the circuits and by the occurrence of sparks at the commutator.

It is generally easy to determine the heating that will occur when the surface by which cooling takes place is known. On the other hand, there has not existed up to the present time any formula which will permit us to determine, even approximately, the value of the angle of lead in terms of the output, or, what comes to the same thing, to estimate the degree of sparking at the brushes for a given strength of current.

Our intention here is to show how we may assure ourselves *a priori* of the satisfactory working of a machine as far as parking at the brushes is concerned.

It can easily be conceived that it is impossible to obtain a complete expression embodying all of the complex conditions which it is necessary to comply with in practice. We must, therefore, content ourselves with a method taking account approximately of the conditions found in actual practice. Such an expression we will proceed to establish.

Figs. 123 to 125 represent three different positions of an armature during a rotation: the first, a position a little in advance of that when a section, *a*, is short-circuited by the brushes; the second, when the current is zero; and the third, the position when the current is reversed in the section.

The magnetic axis of the armature is displaced with respect to the armature, and assumes during the specified movements the position indicated by the numbers I., II., and III.

The speed of relative displacement is not always constant. It is greatest at the moment when the section is short-

FIG. 123.

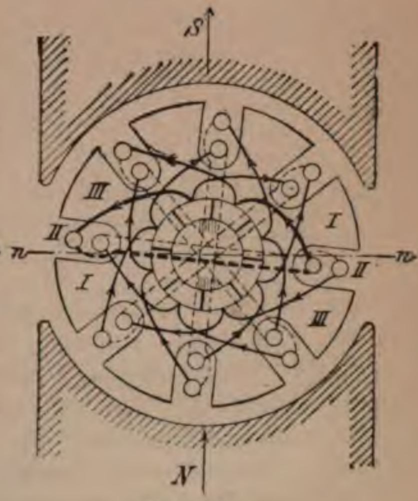


FIG. 124.

circuited, and diminishes more or less quickly according to a law which will be deduced later.

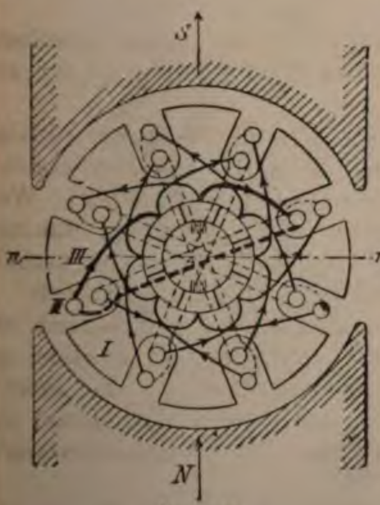


FIG. 125.

If we denote by B_a the induction in the tooth I. of the armature, and by S its section, the magnetic flux then varies from $+ B_a S$ to $- B_a S$. That variation in the flux gives rise, as we know, to the production of an E.M.F. of self-induction which tends to retard the commutation, and which, when the latter has been accomplished, tends to oppose the increase of the current. In order to facilitate the reversal of the current we must shift the brushes in order to produce an E.M.F. which will advance

the moment of commutation and facilitate the subsequent increase of the current to its proper value.

A. General Formulæ.

Let us denote by N the total number of conductors on the surface of the armature;

N_1 the number of sections in the armature (for a smooth armature $N_1 = \frac{N}{N_2}$, for a toothed armature N_1 is the number of teeth);

N_2 the number of sections in the commutator;

E the terminal voltage;

C the total current, and C′ the current in a single conductor;

$2\,p$ the number of poles;

$2\,p_1$ the number of brush-holders;

r the resistance of a coil comprised between two consecutive commutator sections $\left(\frac{N}{N_2} \text{ conductors}\right)$

L the coefficient of self-induction of a coil;

ϵ E the drop of voltage due to the resistance of the armature (0·02 E to 0·05 E);

ϵ' E the total drop of voltage (including that due to armature reaction);

D the diameter of the armature in centimetres;

l the length of the armature in centimetres;

n the number of revolutions per minute.

The current at any instant in a short-circuited coil is determined, if we neglect the resistance at the contact, by the differential equation

$$r\,C' + L\,\frac{d\,C'}{d\,t} = 0.$$

Hence $$C' = x\,e^{-\frac{r}{L}t}.$$

(In the foregoing and some similar equations e is used to denote the base of the Naperian logarithms = 2·718; it must not be confused with the ϵ in equation (29).

The constant x is determined by the conditions at the

instant when the short-circuit is established. When $t = 0$, $C' = \frac{C}{2p_1}$, hence $x = \frac{C}{2p_1}$.

As it will be found more convenient in what follows to introduce the E.M.F.'s, we will express the E.M.F. in a section by the equation

$$E'_1 = E_1 e^{-\frac{r}{L}t} \quad . \quad . \quad . \quad . \quad . \quad . \quad (93)$$

E_1 being the drop in voltage round the section due to its resistance. This expression holds as long as the section remains in the neutral zone.

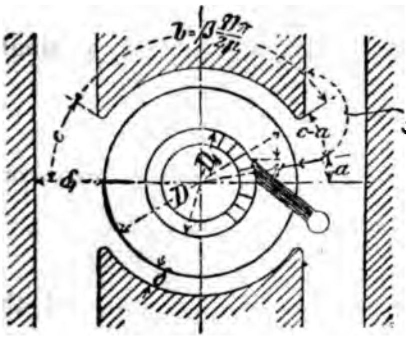


FIG. 126.

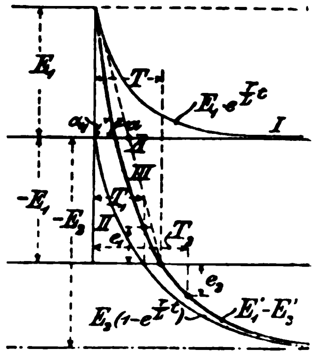


FIG. 127.

If the brushes are shifted in any way—for example, if they are advanced—an E.M.F., E_2, is generated, owing to the conductors in the section cutting lines of force due to the field magnets. This will, in the case considered, augment or diminish the E.M.F. of self-induction, according as the machine is working as a motor or a generator. The current due to that E.M.F. is also affected by the influence of self-induction; as above, we may see that the value of the E.M.F., at any instant, is given by

$$E'_2 = E_2\left(1 - e^{-\frac{r}{L}t}\right) \quad . \quad . \quad . \quad . \quad (94)$$

The current circulating in the coil will, therefore, be equal to

$$C' = \frac{E'_1 - E'_2}{r} \quad . \quad . \quad . \quad . \quad . \quad . \quad (95)$$

From what has been said above, it follows that at the moment of rupture of the short-circuit the current should be equal to $-\frac{C}{2p_1}$, that is to say,

$$E'_1 - E'_2 = -E_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad (96)$$

We deduce from this, replacing E'_1 and E'_2 by their values

$$\frac{r}{L} T = \log_e \frac{E_2 + E_1}{E_2 - E_1} \quad . \quad . \quad . \quad . \quad (97)$$

or, writing $\frac{E_2}{E_1} = \eta$,

$$\frac{rT}{L} = \log_e \frac{\eta + 1}{\eta - 1} \quad . \quad . \quad . \quad . \quad . \quad . \quad (98)$$

In the following table are given the values of $\frac{rT}{L}$ and of $e^{+\frac{r}{L}T}$ for different values of η.

VALUES OF η, $e^{\frac{r}{L}T}$ AND $\frac{r}{L}T$.

η	$e^{\frac{r}{L}T}$	$\frac{r}{L}T$	η	$e^{\frac{r}{L}T}$	$\frac{r}{L}T$	η	$e^{\frac{rT}{L}}$	$\frac{r}{L}T$
1·0	∞	∞	2	3	1·10	7	1·33	0·288
1·01	201	7·6	2·2	2·66	0·98	8	1·28	0·250
1·02	101	4·6	2·4	2·43	0·88	9	1·25	0·220
1·05	41	3·7	2·6	2·25	0·81	10	1·22	0·198
1·1	21	3·04	2·8	2·11	0·75	12·5	1·17	0·160
1·2	11	2·4	3	2	0·69	15	1·14	0·131
1·3	7·6	2·03	3·5	1·80	0·59	17·5	1·12	0·113
1·4	6	1·78	4	1·67	0·52	20	1·10	0·110
1·5	5	1·06	4·5	1·57	0·45	25	1·08	0·080
1·6	4·3	1·46	5	1·5	0·405	30	1·07	0·066
1·8	3·5	1·25	6	1·4	0·336	—	—	—

B. Calculation of $\frac{r}{L}T$.

We have
$$r = \frac{\epsilon 4 p_1^2 E}{N_2 C} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (99)$$

The duration of a contact is evidently

$$T = \frac{60\gamma}{\pi D_1 n} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (100)$$

where γ is the magnitude of the contact surface of the brush

(Fig. 126) and D_1 the diameter of the commutator. The calculation of L need only be performed approximately. We will successively study several cases.

1. *Paccinotti Toothed Armature.*—Let u be the total induction due to unit current flowing in a conductor at the bottom of a slot; we may without great error suppose the magnetic circuit to be comprised in two teeth (Fig. 128) which surround the conductor, the portion of the flux which cuts the other coils being regarded as annulled by the closed circuit formed by the rest of the armature. We shall then have, referring to Fig. 128, and taking l as the length of the conductor,

$$u = \frac{4\,\pi\,l}{10}\left[\int_x^{x_1} \frac{d\,x}{\pi\,x} + \frac{y}{2\,x}\right] = \frac{4\,\pi\,l}{10}\left[\frac{2{\cdot}3}{\pi}\log_{10}\frac{x_1}{x} + \frac{y}{2\,x}\right].$$

In general we may assume that

$$\frac{x_1}{x} = \frac{y}{2\,x} = 3.$$

Moreover, it must be remembered that some lines of force pass from one tooth to another through the space between them. These will cut a number of conductors which becomes

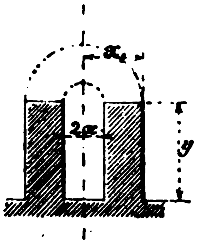


FIG. 128.

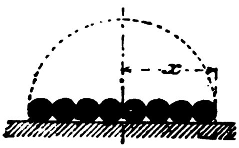


FIG. 129.

less and less as we approach the bottom of the notch. We might, therefore, assume that half the total number of lines of force cut all the conductors in the slots. In that case

$$u = 2{\cdot}3\,l.$$

2. *Armature with Slots partly closed at their Openings.*—A calculation analogous to the preceding shows that we may take as a sufficiently close approximation—

$$u = 3\,l.$$

3. *Tunnelled Armature.*—For this armature the induction is naturally much greater, but the calculation in the most general case is much more complicated. We may, however, assume that

$$u = 3{\cdot}5\ l.$$

4. *Smooth Armature.*—Referring to Fig. 129, we can see that u is immediately given by the equation—

$$u = \frac{4\ \pi}{10}\ \frac{2\ l\ x}{\pi\ x}\ 0{\cdot}5 = 0{\cdot}4\ l;$$

$2\ x$ being that portion of the circumference of the armature occupied by each section.

If we assume in general that

$$u = u'\ l,$$

we shall have for the coefficient of self-induction of each section—

$$\mathrm{L} = u\ \frac{\mathrm{N}^2}{\mathrm{N}_1\ \mathrm{N}_2}\ 10^{-8} = \frac{u'\ l\ \mathrm{N}^2}{\mathrm{N}_1\ \mathrm{N}_2}\ 10^{-8}.$$

Writing $\mathrm{N} = q\ \mathrm{N}_1$ we have

$$\mathrm{L} = \frac{u'\ l\ \mathrm{N}\ q}{\mathrm{N}_2}\ 10^{-8} \quad . \quad . \quad . \quad . \quad . \quad (101)$$

The expression for $\frac{r}{\mathrm{L}}\ \mathrm{T}$ is obtained by combining equations (98) and (101); it is

$$\frac{r}{\mathrm{L}}\mathrm{T} = \frac{\epsilon\ .\ 4\ .\ p_1{}^2\ \mathrm{E}\ .\ \gamma\ .\ 60\ .\ 10^8}{\mathrm{C}\ .\ \mathrm{D}_1\ .\ \pi\ .\ n\ .\ u'\ .\ l\ .\ \mathrm{N}\ .\ q} \quad . \quad . \quad (102)$$

But, from equation (10), we have

$$\mathrm{E} = \frac{\mathrm{N}\ n\ \phi\ p}{60\ p_1\ (1\ \pm\ \epsilon')}\ .\ 10^{-8},$$

in which ϕ is the flux proceeding from one pole, and $\pm\ \epsilon'\ \mathrm{E}$ the total drop in pressure, measured in volts, positive or negative, according as the machine acts as a generator or a motor.

This formula might be written—

$$\mathrm{E} = \frac{\mathrm{N}\ .\ n\ .\ \mathrm{D}\ .\ \pi\ .\ \beta\ .\ l\ .\ \mathrm{B}}{2 \times 60\ .\ p_1\ .\ (1\ \pm\ \epsilon')}\ 10^{-8}. \quad . \quad . \quad (103)$$

Substituting this value of E in equation (102) we obtain—

$$\frac{r}{L} T = \frac{2 \epsilon D \beta B \gamma p_1}{D_1 . C . u' (1 \pm \epsilon') q} \quad . \quad . \quad . \quad (104)$$

The formulæ (102) and (104) allow us to calculate the value of $\frac{r}{L}T$.

Using the value so obtained in conjunction with the values of $\eta = \frac{E_2}{E_1}$ given in the table (p. 214), we may deduce the value of the current in any section when short-circuited for any position whatever of the brushes. To obtain this value of the current it suffices to calculate $\frac{r}{L}$ T from (102) or (104), and to seek the values of η and $e^{\frac{r}{L}T}$ in the table (p. 214) and substitute these in equation (95), taking account of (93) and (94).

C. Lead of the Brushes.

The working efficiency of any machine may be estimated to a certain extent by the aid of the ratio of the angle of lead of the brushes to half the interpolar angle —that is, by the value of $\frac{a}{c}$ (Fig. 130). The more nearly this ratio approaches to unity the greater will be the difficulty of obtaining a position of the brushes where sparking does not occur, the least shift from this position causing an important variation in E_2.

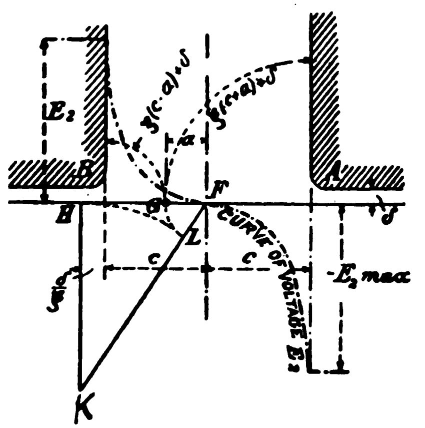


FIG. 130.

Let us first of all determine the value of the flux at a point G of the armature corresponding to a shift, a, of the brushes from the neutral zone. At this point lines of force enter the armature

from the N pole and issue from it to the S pole. Denoting by B the maximum value of the flux between the poles, the flux corresponding to the point G (Fig. 130) will evidently be given by

$$B' = B \frac{\delta}{\xi (c - a) + \delta} - B \frac{\delta}{\xi (c + a) + \delta} \quad . \quad (105)$$

a formula from which E_2 may be calculated.

Further, E_1 may be obtained from C and r; substituting these values in the expression $\eta = \frac{E_2}{E_1}$, we shall have, as a final result of the calculation,

$$\eta = \frac{2 \delta a \xi (1 \pm \epsilon')}{[(\delta + \xi c)^2 - \xi^2 a^2] \beta \epsilon};$$

from which we find

$$a = \sqrt{M^2 + \left(c + \frac{\delta}{\xi}\right)^2} - M \quad . \quad . \quad . \quad (106)$$

where $$M = \frac{\delta (1 \pm \epsilon')}{\xi \beta \eta \epsilon} \quad . \quad . \quad . \quad . \quad . \quad (107)$$

δ, ξ, and β are determined from the dimensions of the machine; ϵ and ϵ', of which the latter might be taken approximately as 2ϵ or 3ϵ, depend on the loss that we admit in the windings; lastly, η is obtained from the table (p. 214).

It is possible to determine a graphically in a very simple manner; this may be done by making (Fig. 130) F H equal to $\left(c + \frac{\delta}{\xi}\right)$ and H K equal to M, and joining K F. If, now, with K as centre, we describe a circular arc, H L, with radius K H, and with the point F as centre, and F L as radius, we describe a second arc terminating at G, then F G is the value of the lead of the brushes.

Equation (106) shows that for machines having a small air-gap the quantity $\frac{\xi}{\eta}$ is negligible in comparison with c.

In the two following tables information is given respecting 21 machines of different kinds; this has been placed at the disposal of the author by the several makers.

VALUE OF $\frac{p}{L}$ T DEDUCED FROM EQUATION (104).

Number.	G = Generator. M = Motor.	Kilowatts	Speed.	Amperes.	Type.	Pairs of Poles.	Winding.	Iron of the Armature.	Observations.
1	G	62·5	600	125	Pl II. Fig. 28	3	Drum	Smooth	Metallic brushes
2	G	5	1,600	50	,, ,, 12	1	Ring	,,	,,
3	G	43·2	750	24	,, ,, 12	1	,,	,,	,,
4	G	10	1,200	100	,, ,, 12	1	,,	,,	,,
5	G	20	800	200	,, ,, 12	1	,,	,,	,,
6	M	10	285	20	,, ,, 22	2*	Series ring	,,	Carbon brushes
7	M	20	440	160	,, ,, 22	2	Drum	Toothed	Fixed carbon brushes
8	G	196	300	370	,, ,, 27	2	,,	,,	,,
9	G	50	600	400	,, ,, 28	2	,,	,,	Metallic brushes
10	G	413	150	7,500	Type ,, 25	12	,,	Smooth	Metal brushes and Mordey's connections
11	G	40	700	320	Pl. II. ,, 25	2	,,	Toothed	Arnold's series-parallel winding
12	M	210	260	150	Type ,, 27	5	,,	Smooth	Carbon brushes
13	M	15	450	30	Iron-clad	2	Series ring	Toothed, apertures half closed	—
14	G	40	300	180	Pl. II. Fig. 26	2	Drum	,,	Series wound with Mordey's connections Metallic brushes
15	G	20	650	1,000	,, ,, 28	3	,,	Tunnelled	Metallic brushes
16	G	2·5	1,300	20	,, ,, †18	1	,,	Toothed	,,
17	G	4·5	1,200	36	,, ,, †18	1	,,	,,	,,
18	G	10	1,000	80	,, ,, †18	1	,,	,,	,,
19	G	10	1,200	1,000	,, ,, †18	1	,,	Tunnelled	,,
20	G	48	500	400	,, ,, 12	1	,,	Toothed	,,
21	G	60	500	500	,, ,, 12	1	,,	,,	,,

* Two series windings spaced with two commutators, therefore $p_1 = 2$. † Upright.

VALUE OF $\frac{r}{L}$ T DEDUCED FROM EQUATION (104) (*continued*)

Number.	N_r	δ in cms.	δ'_1 in cms.	ξ.	D in cms.	β.	Bl.	p_1.	γ in cms.	ϵ (when warm).	D_1 in cms.	C.	u.	$1 \mp \epsilon'$	q.	$\frac{r}{L}$ T.	η.
1	176	1·4	11	2·1	70	0·73	5,100	1	0·9	0·016	50	125	0·2	1·03	2	1·45	1·6
2	46	0·95	11·2	2	24·5	0·75	2,900	1	1	0·035	11	50	0·2	1·07	4	3·85	1·045
3	140	1	12	3	51	0·84	4,100	1	0·8	0·023	35	24	0·2	1·05	8	2·3	1·22
4	50	1	10	2	29	0·72	3,500	1	1·0	0·04	13·5	100	0·2	1·08	3	3·35	1·075
5	72	1·5	11	2	42	0·65	3,000	1	1·0	0·042	20	200	0·2	1·08	2	2·0	1·03
6	113	1·4	6	1·8*	35	0·55	4,400	1	1·0	0·06	26	20	0·2	0·88	12	4·65	1·02
7	65	0·3	9·7	2	50	0·75	8,600	2	1·5	0·023	30	160	2·3	0·95	4	1·06	2·07
8	244	1	30	2·5	115	0·74	6,000	2	2·5	0·02	68	370	2·3	1·04	2	0·85	2·5
9	112	0·75	15	2·1	56	0·615	6,300	2	1·2	0·021	26	400	2·3	1·04	2	0·445	4·5
10	216	2·45	8·8	1·6	237	0·64	6,600	12	3	0·016	170	7,500	0·2	1·03	2	1·1	2
11	61	0·6	11·5	2·3	41	0·66	6,500	1	1·1	0·04	20	320	2·3	1·08	1	0·97	2·2
12	256	2	14	1·8	150	0·72	6,200	1	1·8	0·02	90	150	0·2	0·96	3	3·1	1·1
13	119	0·2	12	2·1	40	0·63	7,400	1	1	0·048	25	30	3	0·90	12	0·735	2·85
14	48	0·5	4·7	1·6	50	0·85	7,000	†1	1·2	0·026	32	180	3	1·06	4	0·254	7·9
15	39	0·15	7·4	2·1	48	0·73	8,000	3	1·7	0·026	27	1,000	3·5	1·05	1	0·75	2·8
16	50	0·35	5	2·35	18	0·51	6,200	1	0·8	0·053	11·5	20	2·3	1·1	8	1·04	2·1
17	44	0·4	5·5	2·35	18	0·51	5,550	1	1·0	0·048	12·5	36	2·3	1·1	8	0·536	3·8
18	54	0·4	6	2·35	24	0·49	7,200	1	0·8	0·030	15	80	2·3	1·06	4	0·35	5·8
19	11	0·4	9	2	25	0·87	4,000	1	2·0	0·035	18	1,000	3·5	1·1	1	0·175	11·5
20	60	0·3	11	3·2	51·5	0·76	5,000	1	1·0	0·036	24	400	2·3	1·07	2	0·298	6·8
21	70	0·6	12	3·2	62·2	0·7	3,950	1	1·0	0·04	29	500	2·3	1·08	2	0·191	10

* Asymmetric magnetic circuit. † $p_1 = 1$, in spite of the presence of four brush-holders, on account of the winding being in series.

VALUE OF a, EQUATION (106), AND $\frac{a}{c}$.

Number.	G = Generator. M = Motor.	$\frac{rT}{L}$	η	ξ	β	ϵ	δ	$(1 \mp \epsilon')$	M	c	$\frac{\delta}{\xi}$	$\sqrt{M^2 + \left(c + \frac{\delta}{\xi}\right)^2} - M$	a	$\frac{a}{c}$
1	G	1·45	1·6	2·1	0·73	0·016	1·4	1·08	36·8	4·95	0·66	37·3 − 36·8	0·5	0·10
2	G	3·85	1·04	2	0·75	0·035	0·95	1·07	18·6	4·8	0·475	19·3 − 18·6	0·7	0·146
3	G	2·3	1·22	3	0·84	0·023	1	1·05	14·9	6·4	0·33	16·4 − 14·9	1·5	0·234
4	G	3·35	1·07	2	0·72	0·04	1	1·08	17·5	6·35	0·50	18·8 − 17·5	1·3	0·204
5	G	2·0	1·3	2	0·65	0·042	1·5	1·08	22·8	11·5	0·75	25·9 − 22·8	3·1	0·270
6	M	4·65	1·02	1·8	0·55	0·06	1·4	0·88	20·5	6·7	0·78	21·8 − 20·5	1·3	0·194
7	M	1·06	2·07	2	0·75	0·023	0·3	0·95	4	4·85	0·15	6·4 − 4	2·4	0·455
8	G	0·85	2·5	2·5	0·74	0·02	1	1·04	11·3	11·7	0·40	16·5 − 11·3	5·2	0·445
9	G	0·445	4·5	2·1	0·615	0·021	0·75	1·04	6·4	8·35	0·357	10·8 − 6·4	4·4	0·525
10	G	1·1	2	1·6	0·64	0·016	2·45	1·03	77	5·6	1·53	77·3 − 77	0·3	0·05
11	G	0·97	2·2	2·3	0·66	0·04	0·6	1·08	4·85	5·5	0·26	7·53 − 4·85	2·58	0·49
12	M	3·1	1·1	1·8	0·72	0·02	2	0·96	67·40	6·6	1·11	68·5 − 67·4	1·1	0·167
13	M	0·735	2·85	2·1	0·63	0·04	0·2	0·92	1·22	6	0·095	6·308 − 1·22	5·088	0·85
14	G	0·254	7·9	1·6	0·85	0·026	0·5	1·06	1·9	3	0·31	3·83 − 1·9	1·93	0·645
15	G	0·75	2·8	2·1	0·73	0·026	0·15	1·05	1·41	3·4	0·071	3·74 − 1·41	2·33	0·685
16	G	1·04	2·1	2·35	0·51	0·053	0·35	1·1	2·88	6·9	0·15	7·63 − 2·88	4·75	0·69
17	G	0·536	3·8	2·35	0·51	0·048	0·4	1·1	2·0	6·9	0·17	7·35 − 2	5·35	0·775
18	G	0·35	5·8	2·35	0·49	0·03	0·4	1·06	2·1	9·6	0·17	10 − 2·1	7·9	0·823
19	G	0·175	11·5	2	0·87	0·035	0·4	1·1	0·63	2·55	0·20	2·82 − 0·63	2·19	0·86
20	G	0·298	6·8	3·2	0·76	0·036	0·3	1·07	0·54	7·5	0·10	7·619 − 0·54	7·08	0·945
21	G	0·191	10	3·2	0·7	0·04	0·6	1·08	0·72	15	0·19	15·2 − 0·72	14·48	0·965

We may remark that in the preceding tables the machines are arranged according to their electrical value; the first eight, however, all of which are sufficiently satisfactory, are arranged indiscriminately. The first eight worked perfectly; the next three worked well enough. As to the machines numbered from 12 to 17, their working was mediocre; lastly, those numbered 18 to 21 could not be used without alterations.

These results might, in general, have been predicted from the values of the ratio $\frac{a}{c}$: as to certain exceptions which occur, they can be easily explained when account is taken of particular circumstances in connection with the various machines. Thus the machines numbered from 7 to 13 worked as motors; the value of the ratio $\frac{a}{c}$ should therefore be very much diminished, for reasons which will be given subsequently.

As to the machine No. 10, for which the ratio $\frac{a}{c}$ is smaller than that corresponding to its place in the table, we may remark that it possessed 24 lines of six brushes, and that, as a consequence, its working depended largely on the adjustment of the brushes. It has, when certain precautions were taken, been found possible to obtain a total absence of sparking in that machine.

Lastly, the imperfect working of machine No. 12 was due solely to the fact that the voltage between two consecutive commutator sections was at a maximum equal to 55 volts, which imposed a condition not taken into account in the preceding investigation.

The lead of the brushes calculated from the formulæ already given, agreed exactly with the results of experiments performed during several years on the machines 20 and 21. The results of these experiments have already been published (see *Electrician*, May, 1893).

No.	Amperes.	Angle of Lead. Calculated.	Angle of Lead. Observed.
20	250	15·1	15°
21	500	26·6°	27°

For greater simplicity it has been assumed up to the

present that E_2 is constant. This assumption is only valid when the angle of lead is small, and when the pole corners are sufficiently distant from each other. Further it is necessary that γ, the arc of contact of the brushes, should be small. If these conditions are not complied with, it is necessary to take account in equation (105) of the variation of the E.M.F. induced whilst the armature section is short-circuited. To avoid unnecessary complications in our calculations, we will content ourselves with the determination of the mean value of E_2.

Calling the linear velocity of the circumference of the armature ω, the formula (105) will take the form

$$B' = B \frac{\delta}{\xi\left(c - a - \frac{\omega T}{2}\right) + \delta} - B \frac{\delta}{\xi\left(c + a + \frac{\omega T}{2}\right) + \delta},$$

and we may find the real value of a by subtracting $\frac{\omega T}{2}$ from the value given by equation (106).

D. Sparking.

Experience shows that the angle of lead and the tendency to sparking are related in a very intimate manner. This may also be easily demonstrated from theoretical considerations. We can see, moreover, without proceeding far into the theory of the subject, that the *degree of sparking produced will vary directly with the output of energy in the circuit which is interrupted, and inversely, in some undetermined manner, with the speed with which that interruption is performed.*

Another method of considering the question of sparking has been suggested by Mr. Thorburn Reid (paper presented to the American Institute of Electrical Engineers, Dec. 15, 1897). That engineer attributes the formation of sparks principally to the exaggerated current density which occurs during commutation, and which fuses, and even volatilises, the metallic surfaces in contact. It is, indeed, easy to see that the current density under the brushes cannot remain constant, since the section of the contact varies in a linear manner with the time, whilst the current curve has an entirely different form—for example, that indicated in Fig. 127.

In order to take account of this important circumstance, we are obliged to introduce the resistances of the contacts into our calculations. Turning to Fig. 131, in which the resistances are represented by r_1 and r_2, we will designate by C′ the current in the coil when short-circuited, and by C_1 and C_2 the current strengths at the two points of collection.

The general formula, according to Kirchhoff's law, will be as follows:

$$L\frac{dC'}{dt} + C'r + E_2 + C_1 r_1 - C_2 r_2 = 0.$$

Supposing the current density to remain constant, it would follow that

$$C_1 r_1 = C_2 r_2,$$

when
$$L\frac{dC'}{dt} + C'r + E_2 = 0.$$

If we express this equation in terms of C′, and replace E_2 by $\eta \frac{C}{2p_1} r$, we shall, after some transformations have been performed, arrive at the formula (98), which we have already considered.

That which has already been said shows that the formulæ already developed are mathematically exact only when the curve for the current is linear. Further, it would be necessary to take account of the maximum current density which the brushes can support. However, the numerous applications of these formulæ which have been made and found in good agreement with the results of experiments, seem to authorise their use when interpreted with a certain amount of latitude. This is the more fortunate as the determination of the maximum current density presents considerable difficulties.

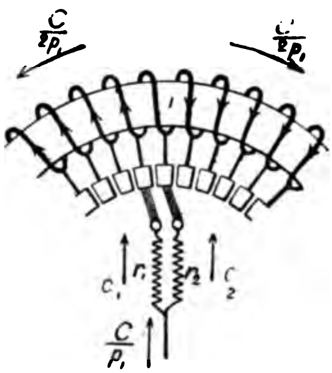


Fig. 131.

It is interesting to examine the last equation for the case where the current follows a linear law. We then have

$$\frac{d\,C'}{d\,t} = -\frac{1}{p_1}\,\frac{1}{T};$$

whence, substituting this value in the above equation—

$$E_2 = \eta\,\frac{1}{2\,p_1}\,r = \frac{1}{p}\left(\frac{L}{T} + \frac{r\,t}{T} - \frac{r}{2}\right).$$

Then for $t = \frac{T}{2}$

$$E_2 = \frac{C}{p_1}\,\frac{L}{T}. \quad . \quad . \quad . \quad . \quad . \quad (108)$$

and

$$\frac{r\,T}{L} = \frac{2}{\eta} \quad . \quad . \quad . \quad . \quad . \quad . \quad (109)$$

formulæ much more simple than (98).

Since it would appear from the preceding that it is always possible to find a certain position for the brushes at which no sparking should take place (on condition that a is less than c), it is necessary to explain why, in practice, all machines, however well made and regulated, give small sparks under the brushes. The reason is to be sought in the exaggerated current density which may occur in the beginning and the end of the commutation, and in the inequality in the resistance of the soldered joint.

The more soldered joints there are the greater will be the sparking, since the difficulty of obtaining a winding such that the resistances of the various sections are equal increases with the number of joints.

In those machines where the armature windings consist of coils wound one upon another without any pretence to symmetry, and thus forming a sort of irregular "chignon" (German, "Knauelwicklung") on either side of the armature, this condition of equality of resistance is impossible to obtain *à priori*. It follows that the position of the brushes to obtain absence of sparking will be different for each section of the commutator. We can therefore only take a mean position where minimum sparking occurs.

Any such irregularities in sections will generally make themselves evident after the machine has had a few hours' run.

The commutator sections which are connected with defective or irregular coils in the armature will be eaten away, whilst those at which the commutation is good will remain polished.

E. Lead of the Brushes for Motors.

If a machine be worked first as a generator and then as a motor, a great difference in the necessary lead for the brushes will be noticed, the motor requiring a backward lead very much smaller than the forward lead of the generator. This is explained in part by the double sign of the quantity $\pm \epsilon$. On the other hand, the difference is greater than is indicated by the formula, and is in reality chiefly due to the sluggishness of the iron in taking up its magnetisation.

To explain this phenomenon, let us consider Fig. 132. It is easy to see that the induction in the iron of the armature, when stationary, will increase from N to *a*, and then decrease from *a* to S in a similar manner. This disposition, however, is modified by the fact that when exposed to a magnetising force, a piece of iron does not instantly assume its final state of magnetisation. It is therefore easy to conceive that the maximum density of the flux does not occur in the neutral zone, *a b*, but in a line, a_1 b_1, displaced in the sense of the rotation of the armature. As a consequence, the angle of lead previously determined must be measured from a point in advance of the neutral zone, *a b*, which will result in diminishing the necessary displacement of the brushes relative to *a b* in the case of a motor, and in increasing the necessary displacement from *a b* in the case of a generator. Unhappily, we must content ourselves with the above explanation, since, in the present state of our knowledge, these

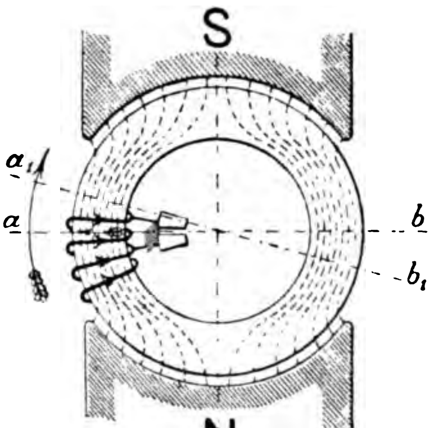


FIG. 132.

complicated phenomena defy calculation, even of an approximate character.

F. Armature Reactions.

We have up to the present considered only those conditions which must be fulfilled in order to obtain sparkless commutation, without considering the "armature reactions" properly so called. These latter play only a secondary part in the phenomena of commutation; further, their relationship with other known phenomena may be easily established.

Armature reactions manifest themselves by a drop of voltage which may attain, under the most unfavourable circumstances, to a value four or five times that of the drop due to the resistance of the armature. Although the drop of voltage thus produced is not accompanied by a loss of energy, it yet diminishes the voltage of the machine and renders it difficult to regulate.

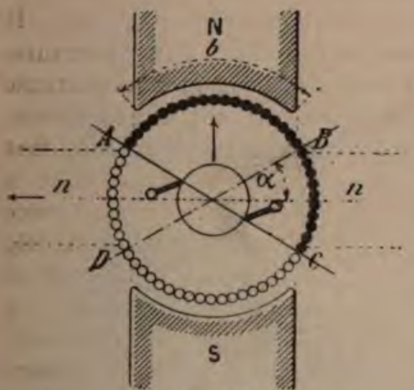


FIG. 133.

Taking account of the direction of the current in the various sections of the armature, it may be seen that the windings may be considered as forming two separate coils, of which the one, A D B C, generates a flux in a line with that produced by the field magnets (inverse flux), whilst the other, A B D C, produces a flux parallel to the plane of the neutral zone (transverse flux).

Moreover, in considering the direction of these fluxes, we arrive at the following conclusions, which are true for either generators or motors:

1. The part of the armature winding A D B C tends to diminish the strength of the poles, N and S. The demagnetising ampere-turns are equal to $\frac{a}{360} \frac{\text{C N}}{p p_1}$, and correspond to a negative flux, ϕ'.

2. The part A B D C produces a new field, ϕ'', parallel to the plane of the neutral zone. Taking account of the polarity of this field and of the lead of the brushes, it will engender an E.M.F. in the conductors which must be added to the E.M.F. produced by the principal field. By this means the effects of the principal field are reinforced.

The production of armature reactions is not confined to the case when the brushes are displaced from the neutral zone; even when no displacement has been made, a distortion of the principal field, together with an unequal saturation in the pole-pieces, will become manifest, as we have already shown (p. 39).

The total permeability of the magnetic circuit being diminished, it follows that a corresponding drop in voltage will be produced.

It is easy to take count of the magnetic flux under the poles by the aid of Fig. 134. Let us consider a point at a distance, y, from the axis, A B; that point is exposed to the magnetising action of the currents carried by the conductors on either side of it.

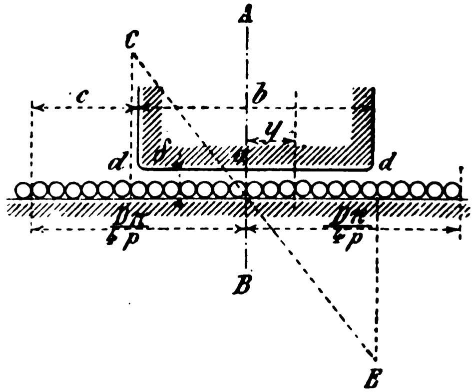


FIG. 134.

Let k be the number of ampere-turns per centimetre length of the circumference of the armature, and let us further suppose that the conductors are traversed by a current producing a field directed in the sense that the hands of a clock revolve. At the point considered, we shall therefore have

$$\left(\frac{D\pi}{4p} + y\right) k \text{ ampere-turns, acting downward, and}$$

$$\left(\frac{D\pi}{4p} - y\right) k \quad ,, \quad ,, \quad ,, \quad \text{upward.}$$

Whence the resultant number of ampere turns $= 2yk$.

The corresponding field, B_l is given by $B_l = \frac{4\pi}{10} \cdot 2yk \cdot \frac{1}{2\delta}$.

Applying this formula to the pole-corners, we have

$$B'_l = \frac{4\pi}{10} b k \cdot \frac{1}{2\delta} = \frac{4\pi}{10} \frac{\beta \cdot D\pi}{2p} \frac{CN}{2p_1 D\pi} \cdot \frac{1}{2\delta}$$

$$= \frac{4\pi}{10} \frac{\beta C N}{4pp_1} \frac{1}{2\delta} \quad . \quad . \quad (110)$$

and for the neutral zone,

$$B''_l = \frac{4\pi}{10} \cdot \frac{CN}{4pp_1} \cdot \frac{1}{2\delta_1} \quad . \quad . \quad . \quad . \quad (111)$$

(For the signification of δ_1, see Fig. 126.)

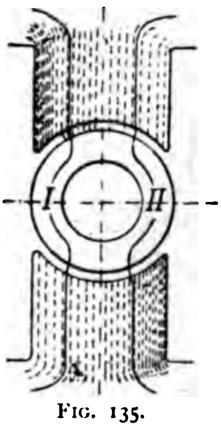


FIG. 135.

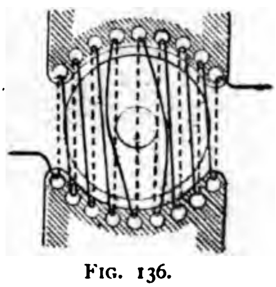


FIG. 136.

This field distortion entails an asymmetrical distribution of the induction in the poles of the field magnets. Referring to Fig. 135, it may be shown, for example, that for the circuit I, the part on the left-hand side of the pole S is subjected to an increased density of flux, whilst the part on the left of the pole N is subjected to a diminished flux

from the field magnet. Further, it is possible to assure ourselves by calculation that the total permeance of the circuit is sensibly diminished; it is the same for the total flux.

To reduce the inverse flux it is necessary to diminish the angle a, which is easily done, remembering what has been previously said as to the determination of that angle. The methods to be used for the reduction of the transverse flux have been considered by the author in his works published in 1891 and 1892, and also in several articles in journals (see *Lumière Electrique*, June, 1893; *Eclairage Electrique*, October, 1896, and March, 1898).

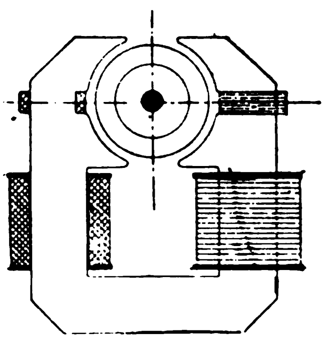


FIG. 137.

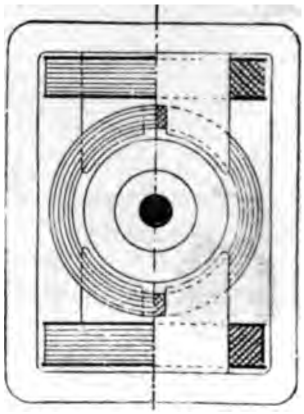


FIG. 138.

We will divide these processes into two class, according as their action is *direct* or *indirect*. In the first class may be included the use of compensation windings, represented in Figs. 136 to 141, and disposed in such a manner that their axis coincides with that of the armature windings, but produces a flux opposed to that due to the latter. It goes without saying that the compensation windings must be traversed by the principal current.

The resultant magnetic force is therefore equal to the difference between the ampere-turns of the armature and of the auxiliary windings.* The compensator windings play

* A similar method has been proposed by Prof. Ryan, nine months after the publication of the author's method (see *Sibley Journal of Engineering*, 1892). On the other hand, it appears from a private communication to the author during the printing of that book that M. C L. Menges, of La Haye (Pays-Bas), had already suggested the same arrangement as that shown in Figs. 139 and 140 in 1884 (number of German patent, 34,465).

a double part; they not only prevent distortion of the field, but they produce, in the neutral zone, magnetic poles which have the same polarity as those due to the field magnets, which they follow in the sense of the rotation.

Leaving on one side the distortion of the field, it suffices, therefore, to give to the compensator windings such a number of ampere-turns that the field produced in the short-circuited armature section has the value which it would have had if the brushes had been displaced to the position where sparkless commutation occurred. In that case the brushes may be allowed to remain in the neutral zone, whatever may be the output of the machine.

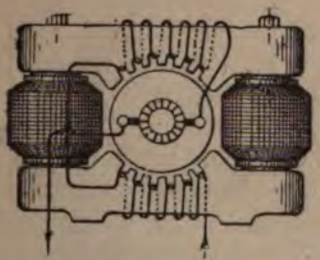


FIG 139.

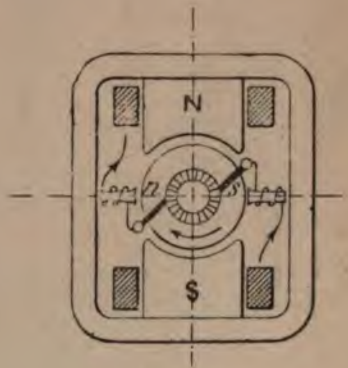


FIG. 140.

The arrangement shown in Fig. 136 is practically advantageous only in the case of machines producing very large currents—several thousand amperes, for instance—and where the number of turns of wire in the compensator are consequently limited. In that case the conductors distributed on a pole should be connected in parallel.

For machines producing feebler currents, the author has employed with success one or other of the variations represented in Figs. 137 and 138, although these effect only a partial compensation of the armature reactions.

Lastly, we will indicate two forms of compensator windings due to M. Menges and Mr. Swinburne, in which the end sought is to diminish the angle of lead and to suppress sparking. This method consists in placing small auxiliary

poles in the neutral zone (Fig. 140), which furnish the necessary field to permit of sparkless commutation.

This last method could, in case of certain machines—*e.g.* those of the Manchester and Thury type—admit a notable simplification which would permit of the entire suppression of the auxiliary windings.

To facilitate the explanation of this, it may be remarked that in the types indicated we might separate the compensating coil into two parts wound in opposite senses on the electromagnets themselves. Let us denote by $C_m N_m$ the ampere-turns of the field magnets corresponding to a magnetic circuit such as II. (Fig. 141), and by $C_m N'_m$ the number of ampere-turns for each winding of the compensator. The ampere-turns acting on the circuit I′ have for value

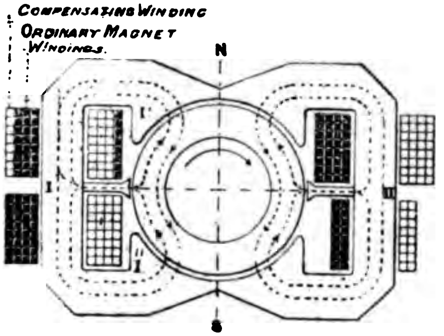


FIG 141.

$$\frac{C_m N_m}{2} - C_m N'_m;$$

those acting on the magnetic circuit I″ have for value

$$\frac{C_m N_m}{2} + C_m N'_m.$$

The sum of the ampere-turns acting on I is equal to $C_m N_m$—that is to say, to the primitive ampere-turns. Since we might include both the ordinary and the compensator windings of the field magnets in a single coil, it is only necessary to arrange the field-magnet windings for the circuit I. in two unequal parts, placed on either side of the small pole, and differing by a number of ampere-turns equal to $2\ C_m N'_m$.

The indirect methods destined to decrease the effect of armature reactions are based on special constructions of the field magnets designed in such a manner that a great

magnetic resistance is offered to the transverse flux, the principal flux remaining meanwhile unaffected.

Thus in Figs. 142 to 144 the desired end is attained by subdividing the electromagnets in different circuits, independent and magnetically isolated. The flux due to the armature reaction is obliged, in consequence, to traverse a number of different air-gaps. (This method when applied to alternate-current motors offers the great advantage of considerably diminishing the self-induction.)

FIG. 142.

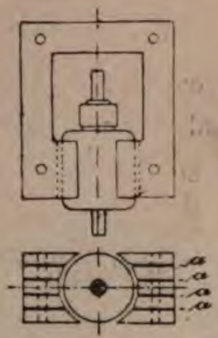


FIG. 143.

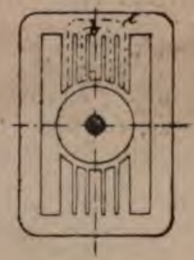


FIG. 144.

A second but less efficacious method consists in furnishing the poles with a number of deep slits. The first machine of this class was constructed by the author in 1890 at the workshops at Oerlikon.

G. Conclusions.

That which has previously been said may be digested into the following rules to be applied to the construction of continuous-current dynamos:

(*a*) The armature windings should be symmetrical, and the number of soldered joints should be reduced to a minimum.

(*b*) The number of commutator sections should be great, and in proportion to the electrical output of the machine. Also the diameter of the commutator should be reduced as much as possible (equation 104).

For high-voltage machines the voltage between two adjacent commutator sections should not exceed 30 or 40 volts.

To obtain this value of the voltage in drum-wound machines the following formula should be used:

$$e_2 = \frac{2\,p\,E}{N_2},$$

which shows that drum-wound machines possessing a large number of poles are not well adapted for the production of a high voltage.

(*c*) The tables given on pp. 219 to 221 lead to the conclusion that a machine is so much the better as the ratio $\frac{a}{c}$ is the smaller. The dynamos for which that quantity is greater than 0·7 or 0·8 will work badly. In practice we should never go beyond the value $\frac{a}{c} = 0{\cdot}5$. Substituting the value 0·7 as the superior limit for a machine in the equation (106), we find

$$\epsilon_{max} = \frac{\delta\,(1 \pm \epsilon')\,1{\cdot}4}{(0{\cdot}51\,c\,\xi + 2\,\delta)\,\beta\,\eta}, \text{ or, approximately, } \frac{\delta\,(1 \pm \epsilon')}{0{\cdot}50\,c\,\xi\,\beta\,\eta}.$$

This equation involves two unknown quantities, of which one, ϵ', might be evaluated *a priori* without great error. The machine No. 19 in particular, which worked still better on half load, gives

$$\epsilon_{max} = \frac{0{\cdot}4 \times 1{\cdot}05}{0{\cdot}5 \times 2{\cdot}55 \times 2 \times 0{\cdot}87 \times 11{\cdot}15} = 0{\cdot}0165,$$

from which we deduce

$$C = 1{,}000\,\frac{0{\cdot}0165}{0{\cdot}035} = 470 \text{ amperes},$$

representing very nearly half of the maximum load.

(*d*) In order that $\frac{a}{c}$ should be small, it is necessary for M to be large. The equation (107) shows that this will be the case if δ is large, whilst ξ, β, ϵ, η are small. If a machine sparks badly, we should be able to improve matters by increasing the air-gap, and eventually in cutting away the pole-pieces—that is to say, in diminishing β. However, since in this case we increase c at the same time, it will be as well to assure ourselves by calculation whether this improvement is likely to prove illusory or not.

CHAPTER VII.

NUOUS-CURRENT DYNAMOS DESIGNED FOR SPECIAL PURPOSES.

A. Arc Light Dynamos.

use of dynamos designed for the purpose of electric g by means of arc lamps connected in series, is not ensive in Europe as in the United States, in spite of imerous arc-lighting installations to be found on the ent. The reason for this must, in all probability, be in the severe conditions existing in Europe, both as s the distribution of the light and the security of g, conditions which may be more easily satisfied by e of arc lamps connected in parallel. Moreover, it is l doubt that the very rapid development in Europe rnating-current systems has contributed not a little to the number of lighting stations where the lamps are ted in series.

ie present chapter we shall therefore develop only the nportant general considerations which must be attended :his kind of distribution, and we will treat specially of st-known American dynamos. We will commence with os supplying each a single lamp.

1. *Dynamo Supplying a Single Lamp.*

mode of lighting is confined almost exclusively to uses. We may find a detailed account of this branch subject in a report by M. A. Blondel, professor at des Ponts et Chaussées, presented at the International ne Congress, which met in London in July, 1893. gh that *savant* has arrived, after several years' study, gative result as far as concerns these continuous-current es, it is nevertheless interesting to follow the reasoning has led to their abandonment.

After the practice followed by the service of French lighthouses, use is made, for the present, of a current strength of from 25 to 100 amperes. Thus, for example, a current of 25 amperes is quite sufficient, with a bi-focal apparatus, to attain the geographical range, and a current strength of 50 amperes enables us, when the air is clear (during about 72 days in the year), to realise, by means of flashing apparatus, a luminosity visible at a distance of about 85 miles: on the other hand, in foggy weather the light corresponding to an arc lamp of 100 amperes is visible only at a distance of about 26 miles. To obtain this variation of current, use is naturally made of two dynamos, each one furnishing 25 to 50 amperes, which may be arranged in parallel when a large current is required. The voltage of the arc varies from 45 to 50 volts: but at the brushes a voltage of from 65 to 70 volts must be produced, according as the regulation of the lamp is effected by hand or automatically. As the resistance of the arc diminishes according as the carbons approach each other, the characteristic of the dynamo should present a form such that the voltage diminishes as the external resistance is decreased—that is to say, as the current increases. A second difficulty lies in the necessary accuracy of regulation of the speed of the machine. In fact, the dynamo should be able to work on a part of its characteristic where the output in watts increases with the current, or at least the output should not decrease with the current: for in the latter case the engine will have a tendency to race when the carbons approach each other, which will lead to a continuous scintillation in the light emitted.

As a result of experiments performed during several years, the engineers of the lighthouse service have found the following inclinations the most favourable for the characteristic curve of a dynamo:

Current strength,	45	amps.;	voltage across arc	43	volts.	Inclination	=	0·5 to 0·6
,, ,,	65	,,	,, ,, ,,	45	,,			
,, ,,	75	,,	,, ,, ,,	48	,,	,,	=	0·45 to 0·55
,, ,,	95	,,	,, ,, ,,	50	,,	,,	=	0·35 to 0·45

When the regulation is effected automatically, we should have, according to M. Blondel, the following values:

Current strength,	25	amps.:	voltage across arc	45	volts:	inclination	=	0·8
,, ,,	50	,,	,, ,, ,,	47	,,	,,	=	0·35
,, ,,	100	,,	,, ,, ,,	50	,,	,,	=	0·15

In using a shunt-wound dynamo it is easy to satisfy these conditions; the only reproach which we can address to these machines is due to their want of stability. To get the necessary inclination in the characteristic, it is necessary to use that part of the curve which shows the machine to be working at nearly maximum output. The least overcharge, which may be produced, for example, if the carbons touch each other, will immediately result in the demagnetisation of the field magnets.

For a series-wound dynamo, the characteristic curve indicates at first an increase of the voltage with the current; a maximum is then attained, after which the voltage decreases as the current increases. A series-wound dynamo can only be used on this latter part of the characteristic. And as, moreover, the drop in voltage is relatively smaller than in the case of a shunt-wound machine, the inclination of the curve must be further increased by the aid of a regulating resistance. The efficiency of the machine is by this means much reduced. The chief difficulty, however, arises from the high current strength which is produced when on short-circuit. Inversely, when the lighting current is interrupted, the engine will race.

Attempts made with compound-wound dynamos have not given good results owing to the great current strength produced on short-circuit. For these reasons the use has been continued in France of the old alternating-current machines, provided with permanent magnets, due to M. de Meritens, except in the case of new installations. The principal advantage accruing to the use of the alternating-current systems is due to the smallness of the drop of voltage across the arc, as well as the diminished value of the adjusting resistance. Taking account of the various losses, it follows from the figures given by M. Blondel that the use of an alternating-current machine permits of the production of double the luminous effect for a given expenditure of energy.

2. *Dynamo Supplying Arc Lamps Connected in Series.*

The arrangement of arc lamps in series has this great advantage, that the voltage for each lamp may be much smaller (42 to 47 volts) than in the case where the lamps are arranged in parallel. This is due to the fact that the lamps exercise a regulating influence on each other.

Arc lamps designed to work in series, regulate themselves for a constant voltage across the arc. The dynamo should therefore be able to maintain the voltage constant whatever may be the number of lamps lighted at any given instant. Hence the voltage should be able to adapt itself at each instant to the number of lamps. Series-wound dynamos, when adapted for the present purpose, work on the descending part of their characteristic. But it may easily be seen that an ordinary series-wound dynamo is not entirely adapted to the conditions of the present problem, even when a resistance is added to the circuit. For that reason we are obliged, if we would nevertheless use such a machine, to return to an artificial regulation, such as that given by a displacement of the brushes or a modification of the number of turns on the field magnets. As we have seen above, we might arrive at the same result by the aid of a resistance wound in parallel with the field-magnet windings; however, it does not appear that anyone up to the present has employed this mode of regulation.

In this class of machines we may include those of the *Excelsior Company*, *Wood Western Company*, *Standard Company*, etc.

It is evidently not wise to be too exacting concerning the efficiency of machines of this class. Indeed, as long as the heating does not exceed the maximum permissible, the efficiency will remain the same whether the adjusting resistance is added outside the machine, or whether it forms part of it. On the other hand, it is most important that we should concern ourselves with the question of sparkless commutation, which should be performed with equal success whatever may be the position of the brushes. This commutation can only be realised with certainty when the armature windings are arranged in such a manner that the brushes can be placed under the pole-pieces, even during the normal working of the machine, since the variation in the field strength is most favourable in this position. This condition assumes the existence of a sufficient amount of self-induction in the armature windings, otherwise the E.M.F. generated in the windings under the poles will be too great. The number of commutator segments is, therefore, intimately connected with the construction and self-induction of the

dynamo, and it must be *neither too great nor too small.* The more the brushes are displaced toward the axis of the poles, the more the influence of the armature reaction will be felt, and the more the field will be weakened. As a consequence, the time during which a coil is short-circuited must be diminished in proportion as the lead is increased. In fact, several constructors use double brushes, of which the relative positions are regulated automatically with the displacement of the principal brushes.

It thence appears that even when the dimensions of the different organs have been judiciously designed, the formation of sparks cannot be completely prevented; it becomes necessary, therefore, to diminish their prejudicial action by the choice of a suitable form of commutator, by obtaining good insulation, and by facilitating the replacement of worn-out brushes, etc. The high voltage used in this case requires an insulation which has been carefully tested in every organ of the dynamo and throughout the commutator. In the end, a bipolar dynamo with a ring armature appears to be the most suitable, notably when the armature is smooth, in conjunction with which certain makers employ a very large air-gap (as much as 30 mm.) Such large air-gaps are rational, and permit us to obtain a homogeneous field even beyond the pole-pieces. But it follows from this that the density of the lines of force in the air-gap is proportionately diminished. That which is most astonishing is the high saturation found in the cores of the armature in these machines, varying from 17,000 to 18,000 lines, and reaching in some Brush dynamos to a value of 25,000 lines. These saturations are necessary, partly to prevent the formation of sparks and partly to produce the drop in voltage; but they present the inconvenience of considerably augmenting the hysteresis losses, and thence heating the machine.* It is thus that in the arc-lighting dynamo due to the Wood system (7,000 volts), a temperature of 93° C. has been observed

* These numbers must not be considered to be absolute, since they are often due to the survival of ancient customs in designing. The best proof is furnished that Mr. Henry S. Carhart's arc-light dynamo, in which the armature saturation amounts to 11,000 lines, works exceedingly well. (See "Theory and Design of Closed-Coil Continuous-Current Dynamos," *Electrical World*, 1894, pp. 113, 151, and 184; *Lumière Electrique*, vol. ii., 1894.)

after a run of 10 hours, the temperature of the dynamo-room being equal to 27° C.

Besides the dynamos we have already considered possessing *closed* armature circuits, there remains a limited number of machines furnished with open armature circuits. To this class belongs the dynamos of the *Thomson-Houston*, the *Brush*. and the *Westinghouse Companies*.

Open windings are characterised by the fact that they form geometrical figures which are not closed. They comprise, further, a smaller number of sections than are found in closed circuits; lastly, they are connected with the commutator in such a manner that each section is taken out of the circuit after the reversal of its current.

On account of the limited number of commutator sections, there can be no question in this case of a *constant* current strength. However, the variations in the current are much smaller than might have been expected with such a small number of commutator segments.

The greatest variations in the current are given by the Thomson-Houston machines, which possess only three commutator segments. The variation in this case amounts to 20 per cent. above or below its mean value. In the Brush dynamo, possessing six brushes, the variation does not exceed 2 per cent.

A valuable property of open-wound dynamos lies in their large drop of voltage, thus permitting a great number of lamps to be simultaneously taken out of the circuit without any fear of the current increasing dangerously. This property does not entirely depend, however, on the nature of the winding; it is partly due to the small number of armature segments.

We will now give a description of the most important dynamos belonging to these two types.

(*A*) *Dynamos with Closed-Circuit Armatures.*

Hochhausen Dynamo (Excelsior Company, New York). (Fig. 145 and 146). — In this machine the displacement of the brushes is effected by means of a small motor, *a*, of which the field magnets are formed by the arms, *b* and *b'*. which may be detached from the poles. At the same time that the brushes are displaced a regulation of the armature windings is effected. For this purpose about 20 wires leave

one of the coils and press against a contact piece which is displaced at the same time as the brushes. The arrangement to effect the displacement, which presents less interest, is only figured schematically in the figure so as not to overload the latter with details.

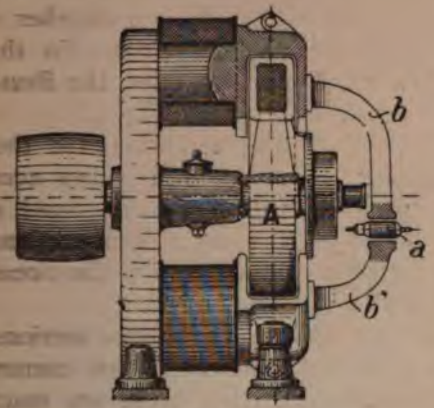


FIG. 145.

The most important part of the regulating apparatus is that constituted by the relays, of which the coils, A (Fig. 146), are traversed by the principal current. The spring, C, of the magnet armature, B, is more or less stretched according to the current. At its mean position the lever, B, touches the terminals, 1 and 2, of the auxiliary motor. The current strength in the motor is, under these circumstances, equal to zero, and its armature remains stationary. If the principal current increases, owing to a number of lamps being taken out of the circuit, the spring is still further stretched, the contact at 2 is broken, and a part of the principal current flows by way of the contact 1 through the armature of the auxiliary motor. A current in the opposite direction is produced when the principal current decreases, and the spring, C, is allowed to shorten, thus breaking the contact 1. As a consequence, in the first case the motor runs forward, in the second case backward.

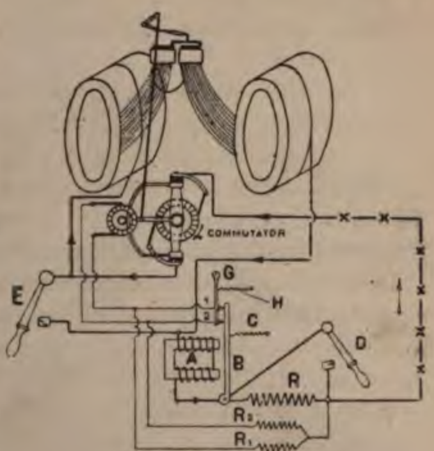


FIG. 146.

The switches, E and D, are used respectively when it is necessary to demagnetise the dynamo by short-circuiting the field magnets, and for short-circuiting the regulating arrangement.

This form of dynamo is often constructed for 5,000 volts.

Wood's Dynamo (Fort Wayne Company).—In this well-known dynamo displaceable brushes are used. Fig. 147 gives a general view of the mechanism used to effect this displacement. Of the eight gear wheels shown, the pinion 1 is keyed directly on to the armature shaft. The pinions 2 and 2′ are carried by a lever, G, in such a manner that, when they occupy their mean position, they do not engage with the wheel 3; but when the position of the lever, B. is altered, one or other of these pinions engages with that wheel in such a manner that the brushes are displaced forward or backward. The position of the lever, B, is regulated by the relay, A. traversed by the principal current.

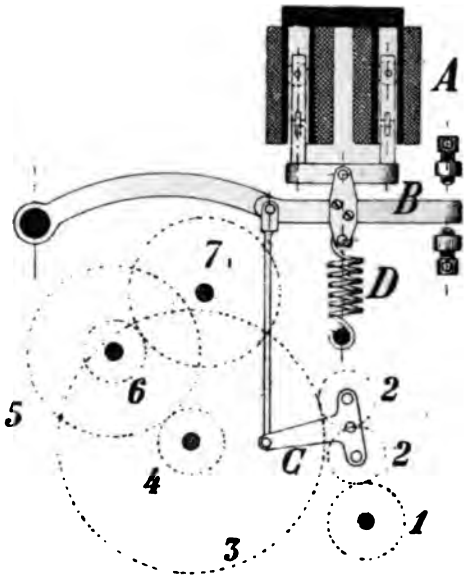


FIG. 147.

It is always very instructive to follow calculations concerning well-designed machines. In this case we have the following information respecting a dynamo for 25 lamps and 2,000 c.p. (Fig. 148)—see *Electrical World*, Feb. 9, 1895:

Voltage = 1,200 volts.

Current strength = 10 amperes.

Speed = 1,000.

Armature: 100 coils, each of 57 turns; wire No. 14 (Brown and Sharp gauge) (1·63 mm. diameter; section 2·07 square millimetres). Resistance between brushes = 7·2 ω when warm.

Volume of iron = 5,550 cubic centimetres; diameter of iron wire = 2·6 mm.

Field magnets: 15 layers of 74 turns per bobbin; wire No. 10 (Brown and Sharp gauge) (2·59 mm. diameter; section 5·23 square millimetres. Resistance of the whole four coils = 15·75 ω when warm.

Drop in Voltage.

		Volts.
Drop due to resistance of armature ...	= 10 × 7·2 =	72
Drop in the field magnets	= 10 × 15·75 =	157·5
Drop in voltage due to armature reaction (estimated)	=	70·5
Total		300

$$\phi = \frac{(1{,}200 + 300)\ 60 \times 10^8}{1{,}000 \times 5{,}700} = 1{,}580{,}000.$$

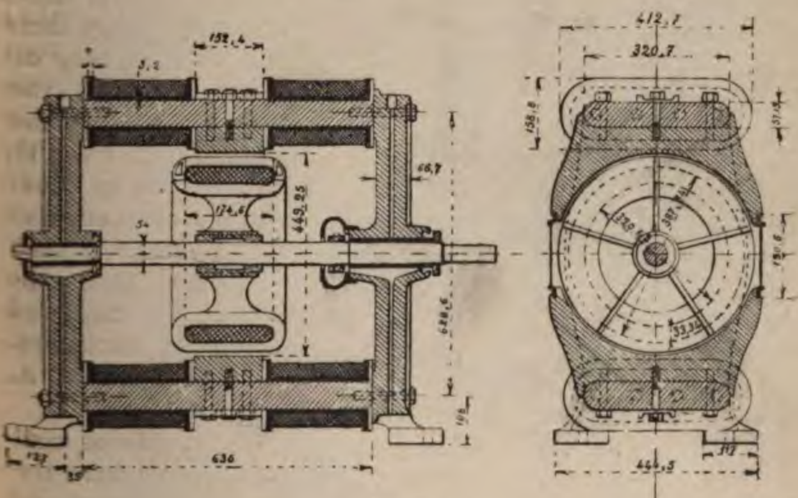


Fig. 148.

Saturation of the Magnetic Circuits.

Coefficient of Leakage.

Section.	B.
Armature, 2 × 49·8 sq. cm.	16,000
Air-gap, 907·5 sq. cm.	1,740
External circuit of the field magnets, 2 × 176 sq. cm....	7,650

Losses.

	Watts.
Armature: copper ... . $72 \times 10 =$	720
Hysteresis ($\eta = 0{\cdot}002$)	
$\times 20 = 16{\cdot}66 \times 10{,}658 \times 5{,}550 \times 10^{-7} =$	100
Field magnets .. .. $157{\cdot}5 \times 10 =$	1,575
Friction (estimated) ... ... =	900
Total	3,295

$$\text{Efficiency } \frac{12{,}000}{12{,}000 + 3{,}295} = 78{\cdot}5 \text{ per cent.}$$

Western Electric Company's Dynamo (Chicago).—The armatures are drum-wound, and comprise only a few coils. As a consequence, in order to avoid leakage due to the high voltage, this machine must be particularly well insulated. The construction of the overhanging commutator in regard to details is not irreproachable; thus the segments are screwed on a wooden hub. The voltage is regulated by the displacement of the brushes. The mechanism employed is represented diagrammatically in Figs. 149 and 150; it was designed by M. Sperry.

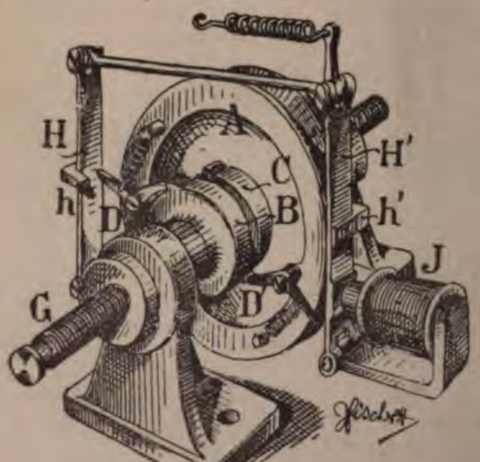


FIG. 149.

B is a nut. The sleeve, C, is keyed on the screw, G. The springs, H and H′, are connected together, and are furnished, at their middle points, with metallic projections, which will be displaced along with the springs, H and H′, and engage or disengage with the catches, D, D′. The position of the springs is regulated by the electromagnet, J, traversed by the principal current; this regulation is effected in such a manner that the catches, D D′, may be, in their mean position.

in contact with the wheel, C, and the nut, B. When, on the contrary, the current strength decreases, the springs are pulled

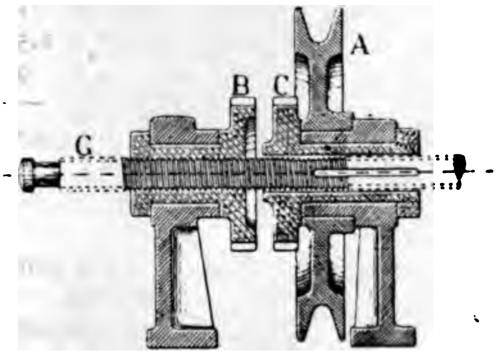


FIG. 150.

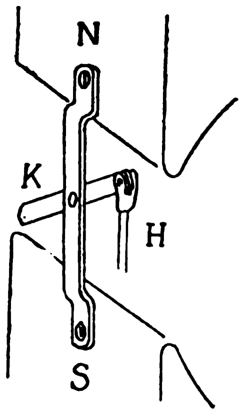


FIG. 151*a*.

toward the left, the catch D is disengaged, and the nut, B, is arrested by friction. The screw, G, is thus turned, and con-

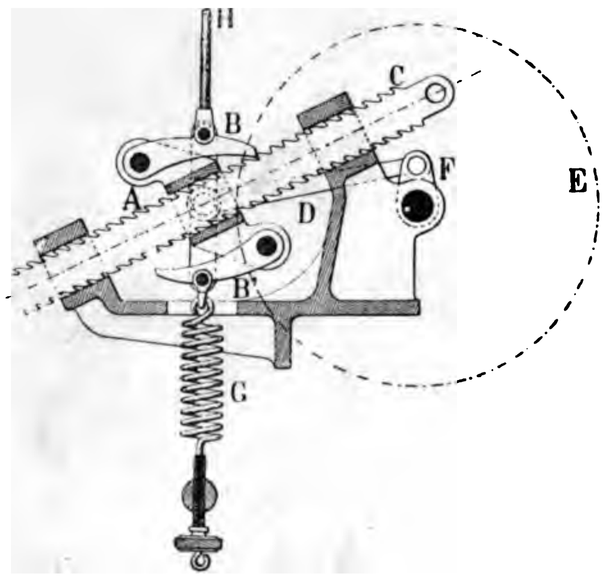


FIG. 151*b*.

sequently displaced from left to right. The opposite happens when the catch D′ is disengaged. The movement of the

screw, G, is transmitted by means of a system of connecting rods.

The Standard Company's Arc Lamp Dynamo.—The armature is constructed like that in a Siemens dynamo possessing interior poles. It may be observed that *the bolts which pass through the midst of the armature are not insulated.* Nevertheless, no undue heating can be observed. The mechanism for the regulation of the brushes is very original (see Fig. 151 *a* and *b*). Its action depends on the attraction of an iron lever, K, suspended between the poles, and connected with the displacement mechanism. The sensitiveness of this arrangement decreases with the degree of saturation of the field magnets.

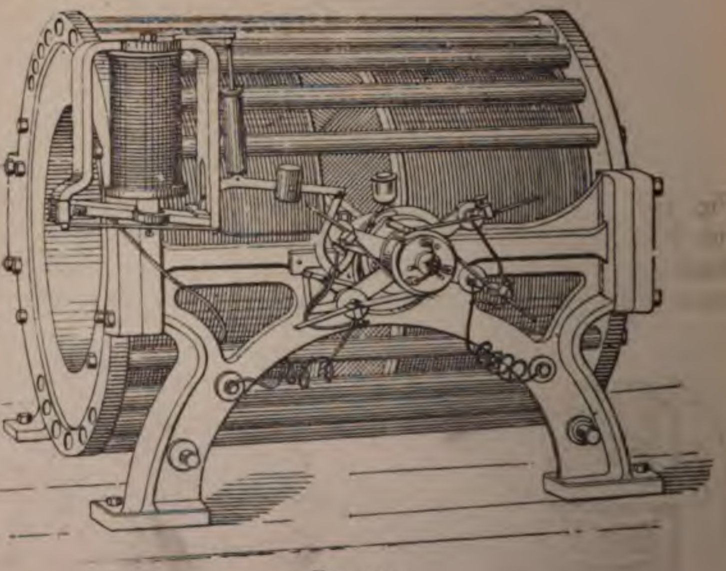


FIG. 152.

Over the rack, C, which is connected with the brush-holders, moves a rocker, A, to which an alternating motion is imparted by the crank, D. According to the position of the rack, C, one or the other of the pawls, B and B′, may engage with the rack, thus displacing it in one direction or the opposite.

(*B*) *Dynamos with Open-Circuit Armatures.*

Thomson-Houston Dynamo.—Figs. 152 to 154 give views and sections of this machine, so remarkable in the history of

the dynamo. The 1·5 kw. and 15 kw. types are furnished with a drum winding, following the scheme shown in Fig. 155; the 17·5 kw. and 25 kw. types have a ring winding (Fig. 156). The scheme of the connections between the regulator, the brushes, and the external circuit is shown in

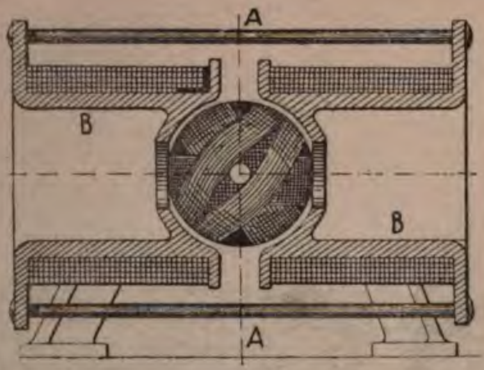


FIG. 153.

Fig. 157. On the commutator, consisting of three sections, rub four brushes, of which each one may be independently displaced; further, the pairs, H J and H_1 J_1, are respectively connected through resistances. The second brush is intended

FIG. 154.

FIG. 155.

simply to diminish the time during which a coil is put out of the circuit. Without this arrangement each coil would be removed from the circuit during two-thirds of a revolution of the armature shaft. The maximum angle between two brushes is, when the machine is working normally, about

60°, and it is reduced by means of the regulator, B, whenever the external resistance diminishes.

For the normal position of the brushes, two armature sections will always be connected in parallel, the third

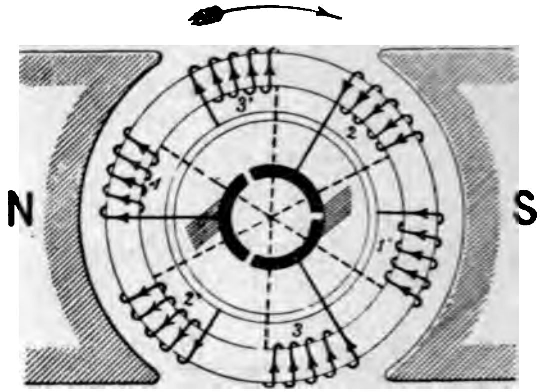


FIG. 156.

section being connected in series with the combination so formed. The relay, C, of which the contact lever, due to the variation in the current strength, is constantly maintained vibrating, is connected in series with the solenoid, A, and traversed by the principal current. The resistance, E, has for its object the prevention of excessive sparking when the relay circuit is interrupted.

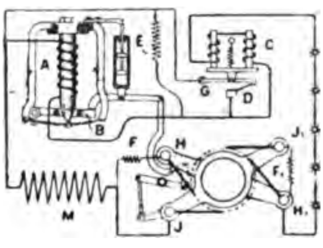


FIG. 157.

We may further notice that the commutator is furnished with a "blower," to diminish the prejudicial action of the sparks naturally produced.

However *bizarre* may be the means employed in this dynamo in order to arrive at the desired end, it cannot be denied that it works very well in practice.

Brush Dynamo.—This machine, which is at least as ancient as that due to Thomson-Houston, presents a double interest: firstly, from the point of view of its construction, which permits of the removal of the armature without dismounting

the field magnets; and, secondly, in connection with its winding.

We will here occupy ourselves only with the winding; constructive details will be given in Chapter IX. These dynamos are made with six or with eight brushes. The overlapping of the commutator segments in this machine is designed to produce the same effects as the double brushes of which we have already spoken. It follows from the Diagrams 158 and 159 that each double coil is put out of

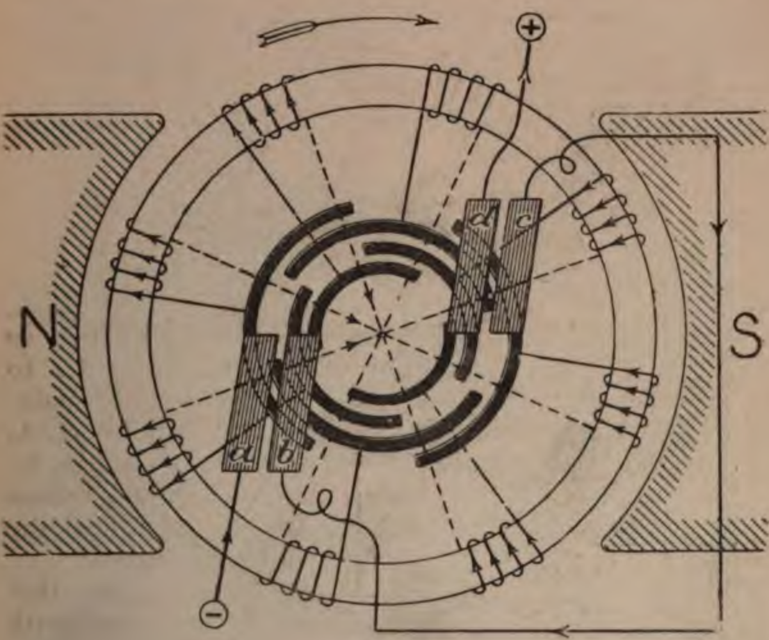


FIG. 158.

circuit during one-eighth of a revolution when the dynamo possesses four brushes, and during one-twelfth of a revolution when six brushes are used. With a winding of twelve armature sections, three of them are grouped in series for any position whatever of the armature, two being connected in series when the number of armature sections is four.

In studying the diagram with attention, it can be seen that the voltage decreases all the time that a section is put out of the circuit. As, before the interruption, two sections

are always connected in parallel, it follows that the one which remains in the circuit receives nearly all the current when the interruption has just taken place, so that only a relatively small amount of sparking occurs.

B. Dynamos for Three-Wire Distribution.

The distribution of current in large electric light installations is generally effected on the *three-wire system* (Fig. 160),

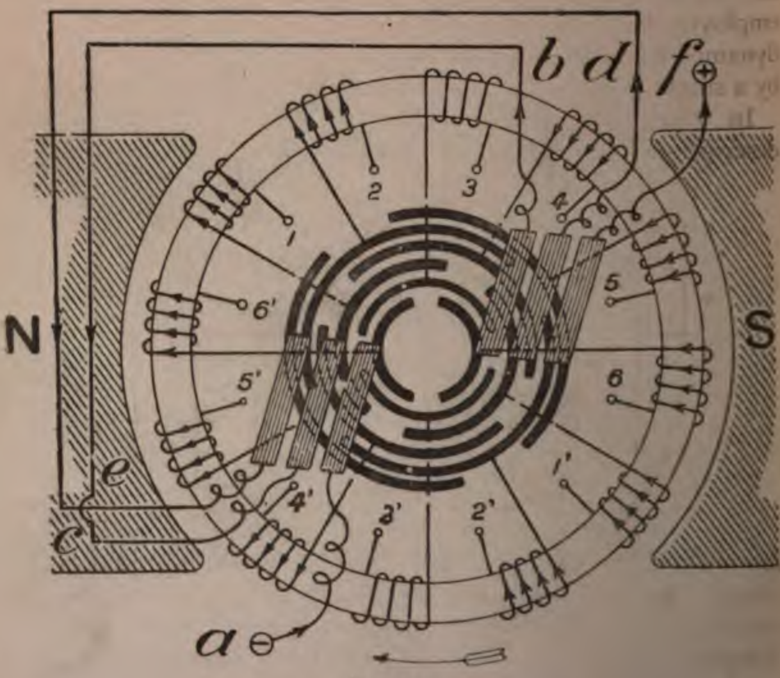


FIG. 159.

of which we have given some details on p. 104. In spite of the increased expense due to the use of two generators, this system gives excellent results because of the economy which may be effected in the copper of the conductors. It presents, however, a certain inconvenience. Indeed, whatever may be the care taken in the original arrangement in order to equalise the load on the two circuits, we cannot avoid at certain hours of the day the production of very different currents in the two branches of the circuit. Therefore, in order to [illegible] he

necessity of running one of the dynamos on open circuit, we connect the positive pole (+) with the negative pole (−) (Fig. 161), and we employ the neutral wire as the return. It goes without saying that we cannot proceed in this manner unless the total output is very small, since, in the contrary case, the loss in the connecting wire would be too greatly increased.

In order to obtain the advantages in working accruing to the use of a single dynamo, together with those due to the employment of the three-wire system of distribution, several dynamos have been constructed in which the current supplied by a single machine may be divided in the necessary manner.

In 1893, Mr. J. A. Kingdon patented a dynamo of this description. It will not be described here since it presents

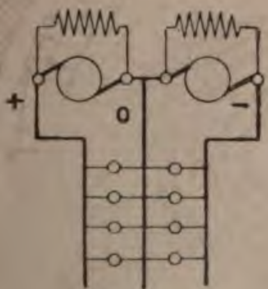


FIG. 160.

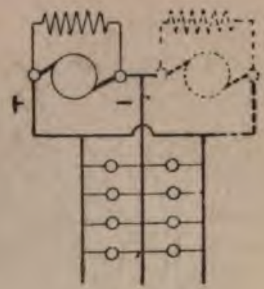


FIG. 161.

few interesting features (see *Lumière Electrique*, March 24, 1894). A real progress has, however, been effected by Dettmar and Rothert; the process used is analogous to that due to Kingdon (see *Elektrotechnische Zeitschrift*, 1897, p. 230). This machine comprises three brushes and four poles, the two upper of these latter possessing a polarity opposite to that of the two lower. The section of the armature core must therefore take such a form (different from that found in ordinary four-pole machines) that it can gather up the whole of the lines of force leaving a pole. The excitation is effected in such a manner that the magnets N_1 S_1 receive their current from the brush O+, whilst the magnets N_2 S_2 are supplied from O−.

Suppose, for an instant, that the brush O is raised; the armature reaction will produce an enfeeblement of the poles N_1 S_1, and a reinforcement of the field due to N_2 S_2. In that

manner the voltage between O and + is augmented, and that between O and − diminished.

It follows that for the excitation of the field magnets N S_2 the voltage on open circuit must be taken into account. When the third brush is lowered, we shall obtain, according as the one or the other branch of the external circuit is overcharged, a reduction in the field strength of N_1 S_1, or an

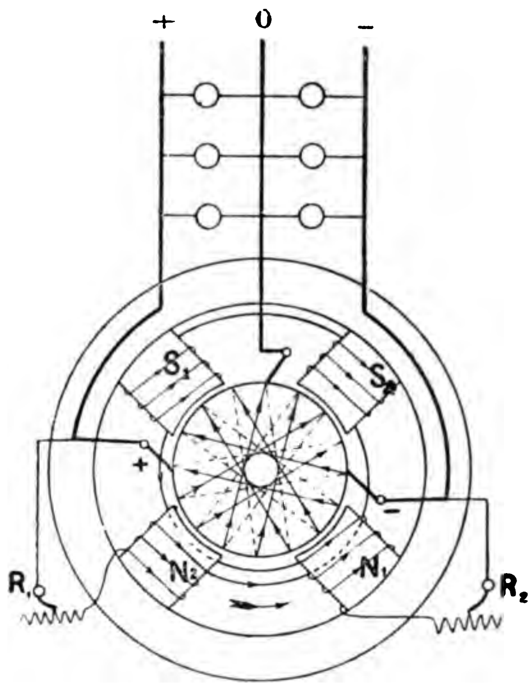


FIG. 162.

increase in the field strength of N_2 S_2. For this reason it is rational to furnish the poles N_1 S_1 with a compound winding. Otherwise we may include a regulating resistance in each of the two windings arranged in parallel.

A dynamo of this kind, of 2 × 110 volts at 340 amperes, worked for several months at the Industrial Exhibition in Berlin, in 1896. Experiments have shown that we may maintain the voltage constant, even when one of the circuits carries no current. This arrangement is not alone applicable

when the machine possesses four, poles; it may be used with any greater number of poles.

A similar result is obtained automatically in the dynamo due to M. Dolivo Dobrowolsky (see *Electrician*, April 7, 1894); however, a sufficient regulation can only be obtained in this machine when the differences are not above 15 per cent.

The principle underlying the construction of this dynamo may be easily understood by reference to Fig. 163. The central wire is connected to a coil, D, which possesses a small resistance but a large self-induction. As a consequence, when the dynamo revolves, an alternating current

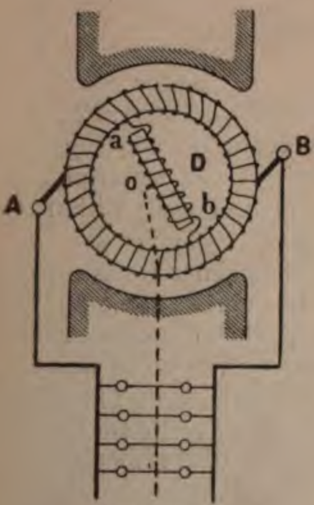


Fig. 163.

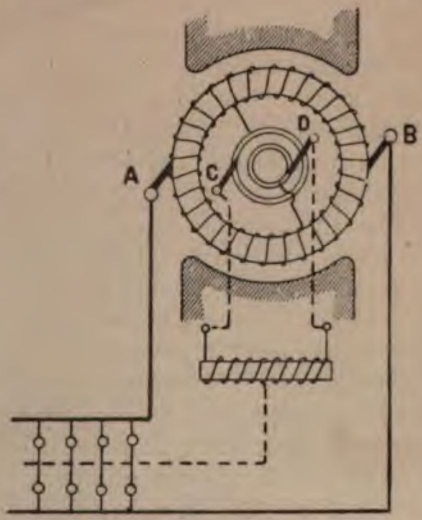


Fig. 164.

of small strength will be produced, its smallness depending on the self-induction of the circuit. On the other hand, a continuous current of any magnitude can flow through it without obstacle.

As it is not always practicable to place the inductive coil, D, in the interior of the armature, M. Dolivo Dobrowolsky employs, in that case, a second arrangement (Fig. 164), in which the coil is placed separately, and connected with the armature by means of two rubbing contacts. (A description of a dynamo built on this principle will be seen in Chapter IX.)

CHAPTER VIII.

PARTS OF CONTINUOUS-CURRENT DYNAMOS.

A. The Armature.

1. *The Shaft.*

The author has often been able to observe that the shafts of dynamos made according to the ordinary rules, sometimes break after having been used for only a short time. Thus five cases occur to our recollection where the shafts of dynamos have broken after working for an interval of from 14 days to a year, without any explanation being suggested by the usual data as to the strength of the material used, since the maximum forces were always well within the limits of elasticity of the substance.

Some years ago, Herr Frederic Autenheimer (then director of the Technicum de Winterthur, but since deceased) published a most interesting study on the *capacity for work of materials of construction*, in which the strength of materials was examined from an entirely new standpoint.* The author of the present work proposed to himself to verify that theory in relation to a great number of broken shafts, and thus to acquit himself of a debt of gratitude toward the memory of a distinguished *savant*, by explaining the applications of that theory, or at least its essential principles, particularly in application to the shafts of dynamos.†

We must, it is true, make certain reservations in respect to the conclusions drawn from this theory, since it only applies to shafts whose diameters are constant, whilst in calculations

* More circumstantial information may be found in *Bulletin des Vereins ehem. Schüler des Technicum Winterthur*, May, 1894, as well as in a memoir by J. Fischer Hinnen, *ibid.*, February, 1895.

† It is only just to say that the work of Wöhler and other engineers had already prepared the way for this theory See especially the work of J. J. Weyrauch, "Stabilité des constructions en fer et en acier et calcul de leurs dimensions," translated and annotated by Michel Svilokossitch, Paris, 1888.

applied to dynamos possessing ordinary shafts we must make use of certain coefficients suggested by experience, the determination of the exact values which should in these cases be used being unfortunately impossible at the present time. We will nevertheless apply this theory, because it permits us to take into account the nature of the consumption of energy in materials for construction with greater certainty than can be done by the aid of the ordinary theories of the strength of materials.

When we submit a bar of length L to a stretching force Z per square centimetre (Z being inferior to the limit of elasticity of the substance) the bar will be lengthened by Δ L, and we may write

$$\frac{\Delta \mathrm{L}}{\mathrm{L}} = \frac{Z}{\mathrm{E}}$$

E being the modulus of elasticity of the substance employed.

The work accomplished during that lengthening is given by

$$a = \tfrac{1}{2} \Delta \mathrm{L} \,.\, Z,$$

whence, in substituting the value of Δ L, we have

$$a = \tfrac{1}{2} \frac{\mathrm{L}}{\mathrm{E}} Z^2.$$

As soon as the stretching force ceases to act it may be considered that the bar returns to its primitive length, or rather (and it is this point that distinguishes the theory of Autenheimer from the older theories), the bar will be found in the end lengthened permanently by a small amount imperceptible to the eye.

The phenomenon is repeated at each change in the direction of the applied force until the lengthening becomes equal to that due to the breaking stress.

Let $a' = \mathrm{K} \frac{\mathrm{L}}{\mathrm{E}} Z^2$ = the quantity of energy lost at each reversal of the applied force, the total loss of energy will be (determining it by means of the breaking stress and its corresponding lengthening)

$$\mathrm{A} = \mathrm{N}\, a',$$

N designating the number of reversals to which the bar may be subjected before it is broken.

When the applied force varies between Z_1 and Z_2 (in the case of the shafts of dynamos Z_1 is equal to the stress due to both torsion and flexure, whilst Z_2 corresponds to the stress of torsion alone), M. Autenheimer has shown, taking account of

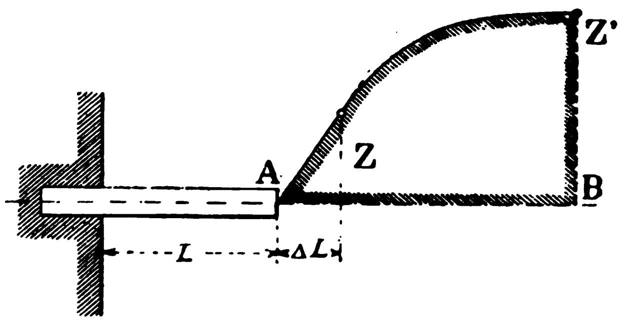


FIG. 165.

the time during which a change takes place, that for shafts of constant diameter

$$A = c\,N\,\frac{Z_1^2 - Z_2^2}{E}\,t \quad . \quad . \quad . \quad . \quad (113)$$

In this formula—

A = the capacity of work, in kilogrammes per centimetre cube = about 7·2 for shafts in wrought iron, and about 6·3 for shafts of cast steel;

c = a coefficient = 0·00094 for wrought iron, or 0·00055 for cast steel;

N = total number of changes in the direction of the applied force which the shaft can resist before breaking, being equal to twice the number of revolutions of the shaft;

E, the modulus of elasticity = 1,800,000 for soft iron, and 2,100,000 for steel;

t = the duration of a change in the direction of the applied force, expressed in hours.

For shafts whose diameters vary, we must, according as the passage from one diameter to another is more or less abrupt, divide the number A by a coefficient which varies between 10 and 40. The experiments of Wöhler, executed during about 40 years on shafts, some of which were used continuously whilst others were occasionally allowed to rest,

have shown that the time which elapsed before rupture took place was, with shafts of variable diameter, from $\frac{1}{10}$ to $\frac{1}{40}$ of that when the shaft had a constant section (see note at bottom of p. 254). In taking account of these facts by the introduction of the coefficient 20, the latter appears to be a rather remote approximation to the proper value; but we must not lose sight of the fact that the diameter of a shaft will only depend on the sixth root of this number. In taking the coefficient two or three times too large we will only commit an error of about 10 per cent.

Equation (113) shows that for the calculation of the "life" of a shaft, it is not the tension Z_1 which must be taken into account, but the difference $Z_1^2 - Z_2^2$.

In calculating the value of $Z_1^2 - Z_2^2$ for different sections of the shaft, it will become evident, as indeed has been shown by experience, that the shafts of continuous-current dynamos generally break between the commutator and the hub of the armature—that is to say, in a place where the torque is equal to zero, or, in other terms: In calculations respecting the shafts of dynamos, *it is not the torque, but the bending moment which must be taken into account.* (See also *American Machinist*, No. 47, November 22, 1894. The rupture of the shaft which is there related could have been anticipated with a certain exactitude by the aid of Autenheimer's theory.)

In a large number of continuous-current dynamos, ranging from 7 h.p. to 260 h.p., we have found, for the part of the shaft mentioned above, the following mean values:

$$Z_1 = 80{,}000 \frac{\text{H.P.}}{n} \frac{1}{d^3}.$$

$$Z_2 = 0.$$

In the first formula, H.P. = the number of horse-power n denoting the speed of the machine. Moreover, we have

$$t = \frac{1}{2\, n\, 60}.$$

Substituting these valuations in equation (113), we obtain, assuming a mean "life" of 30 years for a shaft:

For shafts of wrought iron

$$d = 20 \sqrt[3]{\frac{\text{H.P.}}{n}} = 23 \sqrt[3]{\frac{W}{n}}, \text{ in centimetres} \quad . \quad (114)$$

For steel shafts

$$d = 18 \sqrt[3]{\frac{\text{H.P.}}{n}} = 21 \sqrt[3]{\frac{\text{W}}{n}}, \text{ in centimetres} \quad . \quad (115)$$

In these formulæ d denotes the diameter of the part of the shaft where the total energy consumed is a maximum—that is to say, at the part of the shaft enclosed by the commutator centre. The dimensions in the bearings could be made smaller.

EXAMPLES RELATING TO EQUATIONS (114) AND (115).

Oerlikon Dynamos.

H.P.	n.	d (calculated).	d (executed).
7·1	1,200	33 mm.	40 mm.
15·5	1,000	45	50
30	900	58	56
50	700	79	75
95	500	105	100
200	200	180	140*

* In use this shaft was found to be too weak; it gave origin to an exaggerated bending.

All these shafts were of steel.

The formulæ (114) and (115) in general give shafts too weak for small outputs, and shafts too strong for large outputs. In fact, shafts with a small diameter should have the calculated values increased, because in that case the force due to magnetic traction, arising from faulty construction (for example, from eccentric boring or a defective arrangement of the conductors), will exercise an influence much more important than when the shaft is large. We will return to the force of magnetic traction at the end of this sub-chapter. It goes without saying that the formulæ (114) and (115) can only serve for an approximate predetermination, and that a subsequent verification is always necessary after the armature has been designed. In the case of continuous-current dynamos, we might assume a force of 450 kgrm. to 550 kgrm. per square centimetre, with a normal bending of $\frac{1}{10}\delta$; δ designating the distance of the armature from the field magnets. The bending of a large number of dynamos actually constructed has been found equal to from 0·01 cm. to 0·06 cm., the bending

forces corresponding to from 100 kgrm. to 550 kgrm. per square centimetre. In larger machines it is usually from 400 kgrm. to 500 kgrm.

The dimensions of the other parts of the shaft depend on the diameter of that part inside the centre of the commutator.

The diameter of the shaft at its centre point is generally greater by some millimetres than its diameter in the commutator. For the diameter of the shaft within the bearings, we must take into account the distance between the bearings and the clearance allowed. We might effect a sufficient approximation by arranging that the diameter of the shaft is

in small machines = 1·3 to 1·4 times the diameter in the bearings;

in large machines = 1·1 to 1·1 times the diameter in the bearings;

this bearing being the one situated nearest to the pulley.

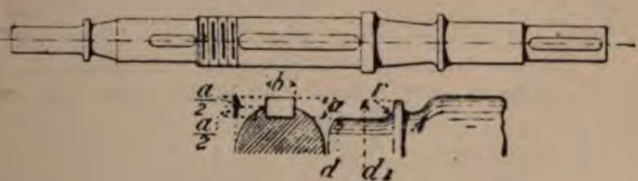


FIG. 166.

The length of the bearings should be made of a sufficient magnitude, since in the contrary case the oil has a too free path along the shaft. Thus it may often be observed that in bearings furnished with a small lubricator, the store of oil will be exhausted in the space of a few minutes.

The armature should be fixed on to the shaft by the aid of either a single large key or two smaller ones. We should use two keys when the metal used is bronze, and when their thickness should be reduced on account of the price of the metal. Insufficient care is often devoted to this part of the subject of dynamo design.

Certain observations made by the author on electric motors for tramways, in which the stress on the keys is, it is true, as unfavourable as possible, have led to a closer examination of the tables in use for the determination of the dimensions of keys. It has been found that the dimension of keys used

in ordinary machines are not well adapted for use in motors. The principal fault to be found with them is in connection with their height, which is too great for a bronze hub, whilst the dimensions of keys calculated for cast iron are too small for bronze. As it is necessary to possess some uniform system, and as, moreover, a certain number of Swiss and German firms have adopted the system of M. Julius Römele, of Fribourg (Baden), it would be well to adopt their system for electric machines, to arrive, in the end, at a greater unification. We will use this under the modified form presented in Table XII.

The modification consists in recommending, for example, a key of 18 mm. by 32 mm. for use, with shafts from 111 mm. to 120 mm. diameter, instead of with those of from 120 mm. to 124 mm. diameter, as recommended by M. Römele: otherwise, M. Römele's dimensions have been maintained throughout. This method, if adopted, would entail the advantage that keys could be purchased ready made of standard sizes. The length of the key is determined by admitting a maximum stress of 4 kgrm. to 5 kgrm. for cast-iron hubs, and 3 kgrm. to 4 kgrm. for bronze ones. If circumstances permit, it is advisable to work below these figures.

Force due to Magnetic Traction.

To determine the force due to magnetic traction arising from wear of the bearings, bending of the shaft, etc., we will make use of the following approximate method. We will suppose, for example, that the centre of the armature of a four-pole machine (Fig. 167) is displaced from its proper position through a small distance x. The first consequence of this displacement will be a modification of the density of the lines of force at the four poles due to the resulting alterations in the magnetic resistance in different parts of the circuit. In order to avoid unnecessary complications, we will suppose that the air-gaps of the poles II. and IV. are unaltered: we may, therefore, alone occupy ourselves with the alterations of poles I. and III.

Let B be the density of lines in the air-gap, before the displacement;

S be the section of a pole;

TABLE OF ACTUALLY CONSTRUCTED DYNAMO SHAFTS.

Horse-Power.	n	$\frac{\text{H.P.}}{n}$	$\sqrt[3]{\frac{\text{H.P.}}{n}}$	Diameter in Middle of the Shaft. d_1 in mm.	Diameter in Larger Bearing d_2 in mm	Length of Bearings.	$\frac{l}{d_2}$	c_1*	Remarks.
2,200	75	29·4	3·1	610	—	—	—	19·7	Generator for tramways, 1,500 kw., West End Co., Boston
5,000	250	20	2·71	—	320 (about)	625 (about)	1·96	—	Westinghouse vertical dynamo, Niagara
600	60	10	2·15	600	400	650	1·63	28	Alternator, J. Farcot system, Champs Elysées, Paris
700	100	7	1·92	457	—	—	—	23·8	Thomson-Houston dynamo, type M B, 10-500-100
600	110	5·45	1·76	300	—	—	—	17	Schuckert dynamo, type J L, 18
700	150	4·66	1·67	240	—	—	—	14·5	Vertical dynamo for aluminium, Oerlikon
325	110	2·95	1·43	—	250	700	2·8	—	Vertical dynamo Δ, Bremgarten, Oerlikon
220	85	2·6	1·37	360	—	—	—	26	Generator for tramways, Alioth
500	200	2·5	1·36	—	230	500	2·18	—	Vertical alternator, La Goule (Oerlikon)
600	300	2	1·26	—	160	500	3·13	—	Fives-Lille (Désiré Korda)
320	235	1·36	1·11	175	—	—	—	15·9	Allm. Svenska Electriska Bolaget
530	400	1·32	1·10	178	—	—	—	16·2	General Electric Company
100	260	0·385	0·73	110	100	—	—	15·1	Six-pole dynamo, Oerlikon
115	435	0·264	0·64	130	100	320	3·2	20·3	Allm. Svenska Electriska Bolaget
110	500	0·220	0·60	135	—	—	—	22·5	Generator for tramways, Alioth
100	500	0·200	0·58	100	90	300	3·34	17·3	Four-pole dynamo, Oerlikon
74	475	0·156	0·54	125	—	—	—	23·2	Electr. Act.-Ges., formerly Lahmeyer
90	600	0·150	0·53	120	—	—	—	22·6	,, ,, ,,
74	600	0·123	0·50	110	—	—	—	22	General Electric Company, Schenectady
45	800	0·056	0·38	70	65	220	3·4	18·4	Four-pole dynamo, Oerlikon
31	780	0·040	0·34	71	60	270	4·5	20·8	G. Kapp, horseshoe dynamo
7·5	1,200	0·006	0·18	50	—		—	27·8	Electr. Act. Ges., formerly Lahmeyer.
4	1,300	0·003	0·14	36	25	80	3·2	25·7	Oerlikon

* Diameter at middle of shaft $= c_1 \sqrt[3]{\frac{\text{H.P.}}{n}}$.

NOTE.—The very considerable variation of the coefficient c_1 could be explained in a certain measure by the ratio of the diameter of the armature to the bore of the field magnets. In the case of the 600-h.p. alternator constructed by J. Farcot at Saint-Ouen, the bore is 5·6 m.; consequently a correspondingly large diameter is given to the shaft.

δ be the breadth of the air-gap;

B_1 and B_3 the densities after the displacement of the armature.

The magnetic resistance of the iron, which might be considered to be constant for a small variations in the lines of force, could be expressed as a fraction of the resistance of the air by writing the total resistance = a × resistance of air.

We shall then have

$$B_1 = B \frac{2 \delta a}{2 \delta a + x};$$

$$B_3 = B \frac{2 \delta a}{2 \delta a - x}.$$

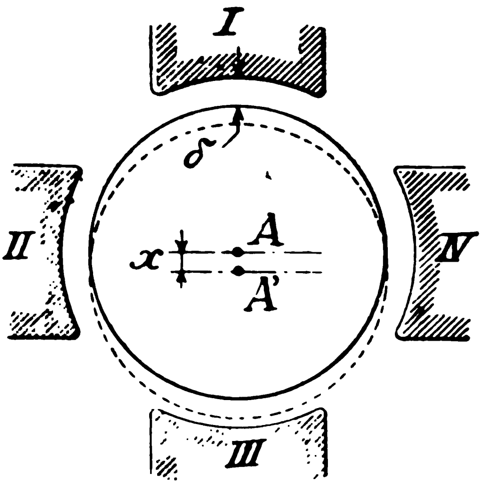


FIG. 107.

The force of magnetic traction will therefore be, according to Maxwell's equation,

$$Z_1 = \frac{B^2 S}{25 \times 10^6} \left(\frac{2 \delta a}{2 \delta a + x}\right)^2;$$

$$Z_3 = \frac{B^2 S}{25 \times 10^6} \left(\frac{2 \delta a}{2 \delta a - x}\right)^2.$$

The downward force which will be exercised will consequently be (neglecting x^2 in comparison with $4 \delta^2 a^2$)

$$Z = Z_3 - Z_1 = \frac{B^2 S}{25 \times 10^6} \frac{x}{\delta a} A \quad . \quad . \quad (116)$$

The constant A is, in the case we are now considering, equal to 2.

In making a similar calculation for the case where the centre of the armature is displaced at an angle of 45° with respect to the axis of the field magnets, we should find A = 2·8. For any given number of poles we might make use of the following table.

TABLE OF VALUES OF A.

Number of Poles.	A.	Remarks.
4	2	Displacement along axis of field magnets
4	2·8	Displaced along neutral line
6	6	,, ,, axis of magnets
8	9	,, ,, neutral line
12	15	,, ,, ,,
16	20	,, ,, ,,

Example.—Let us suppose that the shaft of a four-pole 50-kw. dynamo, possessing a crown of poles in two pieces, is bent by 0·5 mm. ($x = 0·05$).

The weight of the armature = 800 kgrm. Further, δ = 0·5 cm.; $a = 2$; S = 950 square centimetres; B = 7,000.

In this case A = 2·8.

We therefore have

$$Z = \frac{7{,}000^2 \times 950}{25 \times 10^6} \cdot \frac{0.05}{0·5 \times 2} \, 2·8 = 260 \text{ kilogrammes.}$$

$$= \text{one-third weight of armature.}$$

(We can easily see that this number might be doubled when the bushes are worn.)

In symmetrical bipolar machines, a displacement of the centre of the armature parallel to the axis of the field magnets gives rise to no notable modification of the lines of force; thus, in this case, no tractive force is produced. But the case is different when the displacement is parallel to the neutral line.

When the field magnets are not arranged symmetrically, as is the case in dynamos with horseshoe field magnets (Fig. 168), the magnetic axis is found to be situated a little below the horizontal line *a b*, on account of the variable

length of the lines of force. The downward tractive force thus produced will be equal to

$$Z = 2\,Z_1 \sin \alpha.$$

In this formula it remains to determine α.

When the journals are not cast in one piece with the bedplate, we could easily obviate this inconvenience by raising them by means of wrought-iron wedges. In this manner we could, in certain cases, compensate for a certain part of the weight of the armature. In four-pole dynamos, carrying more than two brushes, this method is not always

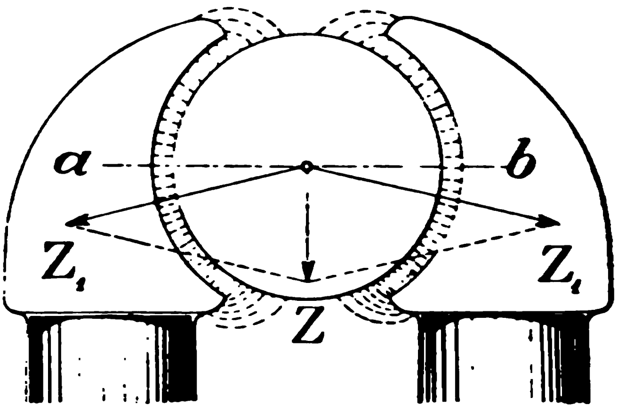


FIG. 128.

applicable, since in that case the different circuits may be unequally loaded. We should use this method only when the armature is furnished with a wave winding (Figs. 16, 28, and 29). The magnetic tractive force exercises a most important influence in the case of very large dynamos worked by steam-engines, in which the centre of the armature will be displaced at each stroke of the piston. Dynamos of this kind should, in consequence, have an air-gap sufficiently broad, or the intensity of the field should be reduced proportionately. The same result is attained in the workshops of J. Farcot, at Saint-Ouen, by a particular disposition of the field magnets, all the poles of the same sign being arranged on the same side of the armature (see Chapter IX.).

Equation (116) shows that the magnetic tractive force increases, with a given length of the armature, a little more rapidly than in proportion to the diameter. But as the weight of the armature increases very nearly as the square of the diameter, the influence of the magnetic traction diminishes as the dimensions of the armature are increased.

2. *Bearings.—(A) Ordinary Bearings.*

The length of the bearing depends on the admissible dissipation of energy by frictional heating, per square centimetre of the bearing surface (or specific dissipation by heating).

Let us denote by

d, the diameter of the shaft in centimetres;

l, the length of the bearing;

P, the pressure on the bearing, resulting from the weight of the armature and the pull of the belt (see p. 55);

f, the coefficient of friction;

A, the specific dissipation admissible, per square centimetre.

In order that the bearings should not be heated, we must have

$$\frac{d \, \pi \, n}{60 \times 100} \mathrm{P} f \leqq d \, l \, \mathrm{A};$$

or,

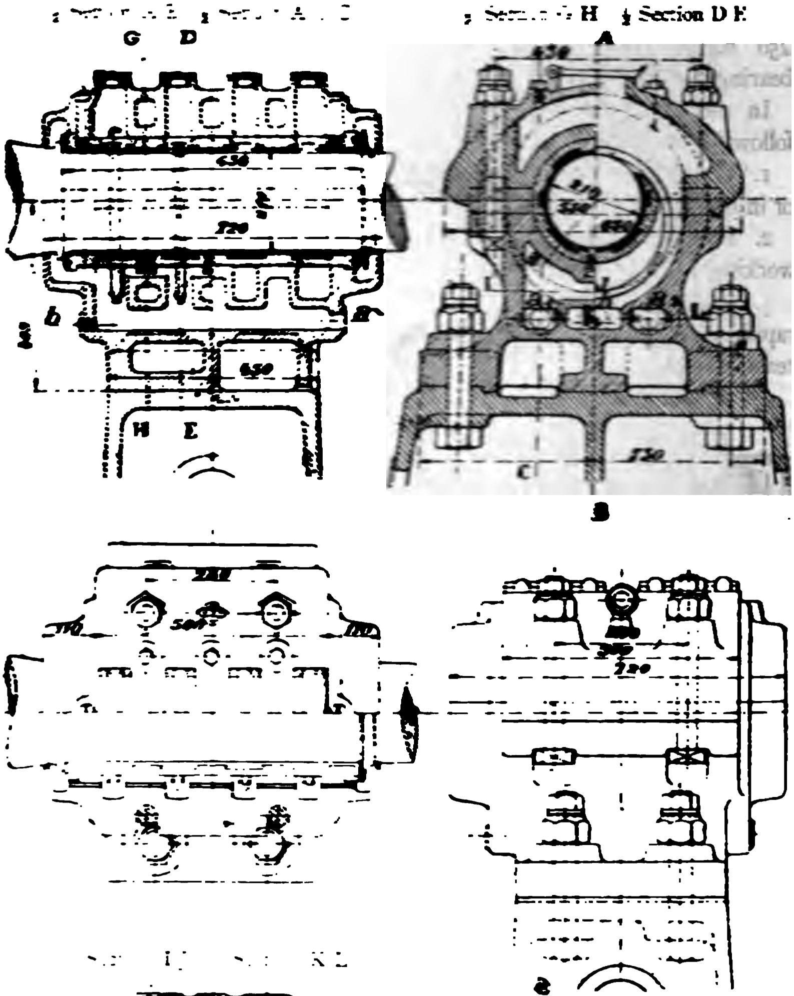
$$l \geqq \frac{\mathrm{P} f n}{1{,}900 \, \mathrm{A}} \quad . \quad . \quad . \quad . \quad . \quad (117)$$

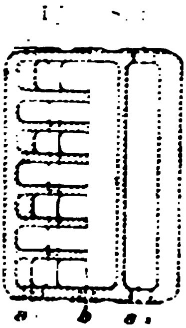
f will vary according to the nature of the oil used and the speed employed, between 0·05 and 0·08; A should not be greater than 1 kilogramme-metre per square centimetre, and it is only when the lubrication is very good that we could allow a value of A = 1·1 to 1·2 kilogramme-metre.

Generally we take

For very small machines	$l = 3{\cdot}5\,d$ to $4\,d$
For medium-sized machines	$l = 2{\cdot}5\,d$ to $3\,d$
For large machines	$l = 2\,d$ to $2{\cdot}5\,d$

Almost all modern dynamos are furnished with one or two and sometimes more lubricating rings, arranged along the bearing. Experience has shown that we can *with a single lubricating ring thoroughly lubricate a bearing* whose length does





Water-jacketed bearing of a dynamo of 1,000 h.p., designed by the Author and made at the works of J. Farcot.

FIG. 169.

they can be adjusted in any position. This is the case with a bearing constructed several years ago by the Westinghouse Company (Fig. 172). To avoid the necessity of spherical boring, which is hard to perform, the Crocker-Wheeler Company, who construct small motors, fill the space between the bush and the body of the bearing with a fusible composition (Fig. 173).

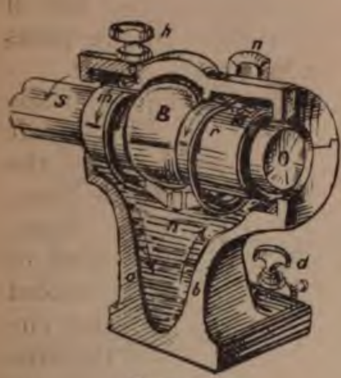


FIG. 173.

A simple bearing of this kind is constructed by the *Actien-Gesellschaft Sächs. Electricitäts-werke,* formerly Pöschmann and Company. Other types of bearings are described in Chapter IX.

American constructors often employ an excellent plan in order to obtain absolutely true bushes; a similar plan has

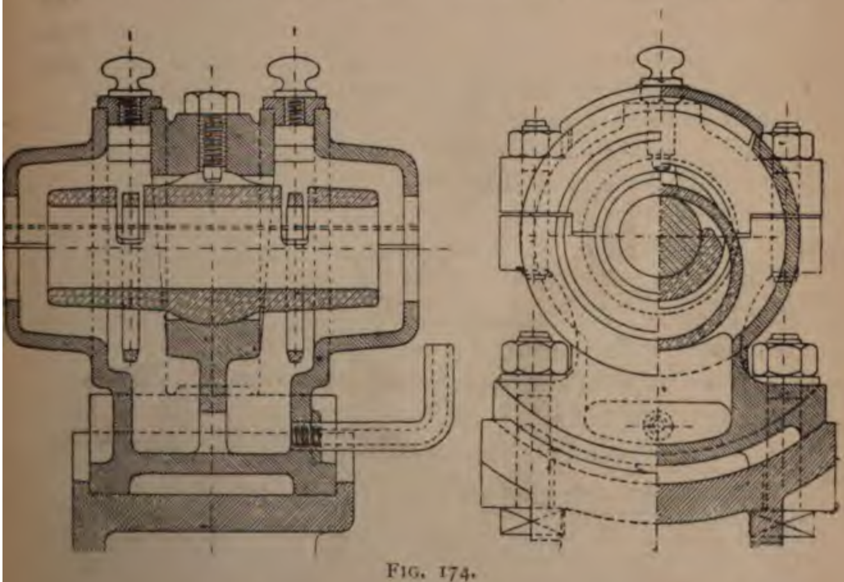


FIG. 174.

been used for the last five years at the Oerlikon workshops. For this purpose the bushes are not drilled, but an alloy is

poured around a core placed along the axis of the bush, and which may be displaced in a guide, *a* (Fig. 175). At the extremity of the cylindrical portion this core is furnished with a sharp edge, *f*, and a cone, *d*. The cylindrical portion has a diameter equal to that of the aperture required. After the alloy has been cast, it is allowed to cool a little, and then the core is revolved. The surface of the cushion is finally left very hard and polished like a mirror.

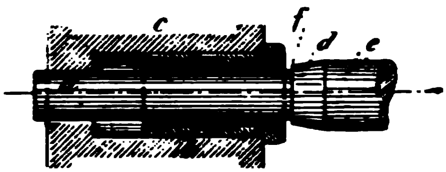


FIG. 175.

This method presents great advantage when it is necessary to replace a bush.

(B) Ball Bearings and Roller Bearings.

The numerous applications which have been made of ball and roller bearings have naturally attracted the attention of dynamo makers. However, attempts which have been made in this direction have not always been crowned with success. It appears, therefore, that some attention to the particulars concerning these bearings may be useful.

The principal difficulties encountered in the use of ball or roller bearings are as follows:

1. The necessity of avoiding the noise produced by the great speed with which the shafts turn.

2. The insecurity of working due to the possibility of the crushing of the balls.

3. The high prices of ball or roller bearings.

It must also be added that the friction in bearings of this class is, in the general case, greater than that which one would be led to expect from the catalogues of some of the makers.

The two first-mentioned faults are found most noticeable when the balls or rollers touch, since in that case the

relative velocity of the surfaces touching is doubled. As a consequence, bearings so constructed will not be found suitable for dynamos. In more recent bearings it has been attempted to avoid rubbing friction, substituting rolling friction in its place.

Supposing that this condition could be fulfilled, the loss due to friction, for a pressure P, could be determined in the following manner:

$$P' = \frac{0{\cdot}05\ P}{R};$$

R being the radius of the rollers in centimetres.

This formula is applicable to the rolling of iron railway carriage wheels on iron rails, where R = about 50 cm. For hard rollers and bushes carefully polished, the friction could perhaps be taken three or four times smaller.

Suppose, then, that the diameter of the shaft = 5 cm. and that of the rollers = 0·75 cm., we shall have

$$P' = \frac{0{\cdot}05\ P}{0{\cdot}75 \times 3} = 0{\cdot}022\ P,$$

whilst, for ordinary bearings, $P' = 0{\cdot}06\ P$.

Moreover, the respective velocities of the periphery of the shaft and of the centre of a ball are in the ratio 2 : 1. Hence the friction is, in the most favourable case, equal to

$$\frac{0{\cdot}022}{0{\cdot}06}\ \tfrac{1}{2} = 0{\cdot}183$$

of that in ordinary bearings.

However, since it is almost impossible to entirely avoid rubbing friction, the true ratio is less favourable.

The Roller Bearing Company, who have studied this subject very completely, and whose bearings are amongst the best on the market, have found that the reduction of friction is between 15 and 20 per cent. during the movement, and from 60 to 80 per cent. at the instant of starting. On the other hand, the expense of the lubricating oil is reduced by 25 to 50 per cent.

According to the information supplied by that company, the rollers of a bearing on which the pressure is 6,000 kgrm. and the shaft makes 500 revolutions per minute, should have

a length of 20 cm. For smaller bearings with shafts of from 5 cm. to 10 cm. diameter, the length of the rollers varies between 2·1 and 1·6 of the diameter of the shaft. The number

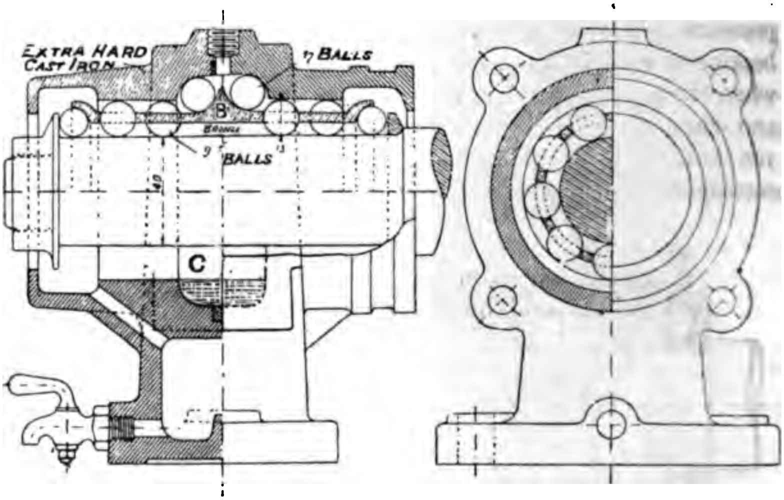


FIG. 176.

of rollers is from seven to eight. Figs. 176 and 178 show some types of roller and ball bearings.

Fig. 176 shows a bearing designed by the author, and is employed in the machine of 4·5 kw. described on p. 173. To

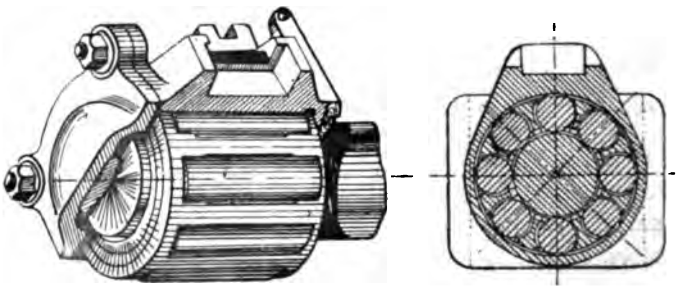


FIG. 177.

hinder the occurrence of contacts between the balls, these latter are contained in a bronze socket pierced with holes. The case is designed to prevent the sliding of the shaft in a

direction parallel to its axis. The oiling may be effected either by the means of a dropping lubricator, or by immersing the disc, B, in the oil reservoir, C.

In the bearing of the Roller Bearing Company (Fig. 177) the balls are replaced by rollers which can endure a greater pressure without injury. A suitable modification of this bearing is well adapted for use with railway carriages, notably when the pressure does not exceed 400 kgrm. for each bearing, and when the speed of the axle is limited between 60 km. and 100 km. If the diameter of the wheel is about 1 m., the corresponding speed is 320 to 530 revolutions per minute.

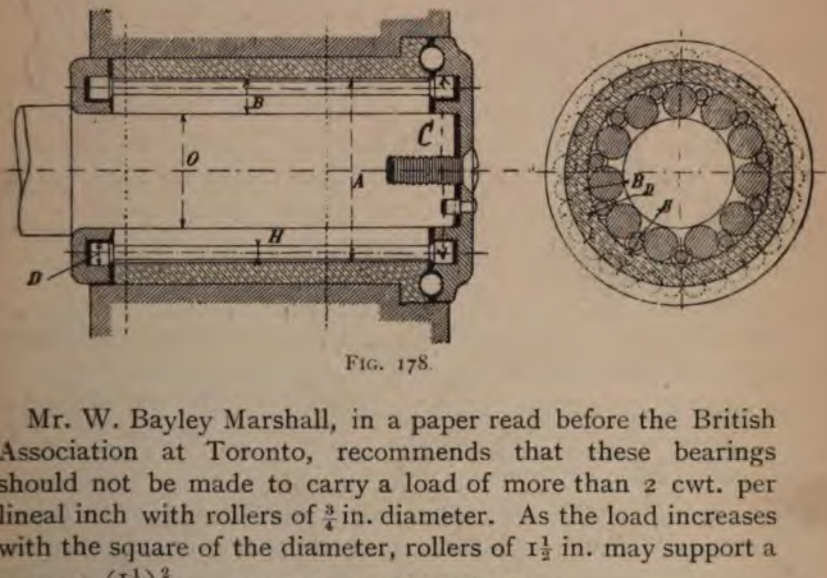


Fig. 178.

Mr. W. Bayley Marshall, in a paper read before the British Association at Toronto, recommends that these bearings should not be made to carry a load of more than 2 cwt. per lineal inch with rollers of $\frac{3}{4}$ in. diameter. As the load increases with the square of the diameter, rollers of $1\frac{1}{2}$ in. may support a load of $\left(\frac{1\frac{1}{2}}{\frac{3}{4}}\right)^2 \times 2 = 8$ cwt. per lineal inch.

In the type shown in Fig. 178, patented by M. G. Philippe, of Paris, the rubbing friction is avoided in an ingenious manner by means of intermediate rollers. To fulfil this condition we must have

$$O : H = C : D.$$

(C) Footstep and Collar Bearings.

Dynamos with vertical axes are often designed to be coupled directly with turbines. In many cases the construction of

the turbines is adapted to compensate for the weight of the moving parts by the hydraulic counter-pressure, and the construction of the bearings is in this manner considerably simplified. This arrangement is often preferable to the others. But there also exist exceptional cases where the constructor of the dynamo must arrange to compensate for the weight of the armature, which is not always possible by the use of a footstep bearing, since the weight and the speed are often considerable.

At the Oerlikon workshops a simple and elegant solution of this problem has been effected in many cases by employing magnetic pivots (Swiss Patent No. 7,610, November, 1893), of which the calculation may be effected by the aid of equation (87). (The firm of J. Farcot, at Saint-Ouen, Seine, has patented (No. 239,191, June 11, 1894) and employed with success a most simple arrangement, which presents the advantage, among others, that hysteresis losses in the plate which is keyed on to the shaft and attracted by an electro-magnet supplied with a single winding are avoided.)

To be sure of success the following precautions should be attended to:

1. The force of magnetic attraction depends on the square of the interpolar distance. As a consequence we must exactly limit the free play, whether downwards or *upwards*, by the aid of an appropriate footstep bearing: this precaution is the more necessary when the beams carrying the dynamo are rather light and exposed to bending.

2. The case of the turbine is deformed by the pressure of the water, in such a manner that the pressure transmitted to the pivot is in reality much greater than the weight of the armature together with that of the shaft, and, eventually, that of the turbine.

As a consequence, we should, in every case, include in the magnetic circuit of this arrangement a regulator which allows us to modify the current strength between limits sufficiently remote.

For footstep bearings, Mr. J. J. Reiffer has given the following table ("Einfache Berechnung des Turbinen," published by A. Raustein, Zurich). The diameters given are only applicable to footstep bearings in which, as well as in the

contact plate, small holes of from 5 mm. to 10 mm. have been pierced.

FOOTSTEP BEARING (DIAMETER IN MILLIMETRES).

Force in Kilogrammes.	Revolutions per Minute.					
	Up to 120	150	200	300	400	500
1,000	40	42	46	53	59	63
2,000	58	60	65	75	83	88
4,000	83	85	92	103	118	125
6,000	100	102	112	130	143	152
8,000	114	118	130	150	165	176
10,000	130	133	146	167	184	—
12,500	145	150	165	190	—	—
15,000	158	160	178	—	—	—
17,500	172	175	—	—	—	—
20,000	185	—	—	—	—	—

When the turbine is suspended from the dynamo, the preference must be given to a collar bearing. A bearing of this nature is represented in Fig. 246. The weight suspended was, in this case, equal to 350 kgrm., the number of revolutions being equal to 1,200 per minute. The collar had the following dimensions: external diameter = 92 mm., internal diameter = 44 mm. An experiment extending over two hours has shown that a motor furnished with a collar of this nature could work without undue heating and without a magnetic pivot; the dissipation allowed was 1·3 kilogramme-metres per square centimetre. For normal working we need not, however, exceed a value of 1 to 1·2 kilogramme-metres.

Ordinary and Grooved Pulleys.

The thickness of the belt is given by the formula

$$g = \frac{\text{H.P.}}{\gamma\, b\, v} \text{ in centimetres.} \quad . \quad . \quad . \quad (118)$$

In this formula we have designated by

H.P. the horse-power transmitted;

b, the breadth of the belt in centimetres;

v, the speed in metres;

γ, a coefficient which is, according to M. Reuleaux,

For hide belts ... ... = 0·16 to 0·30,

„ cotton belts... ... = 0·11 to 0·21,

„ caoutchouc belts... = 0·15 to 0·25.

Simple belts have a thickness of from 4 mm. to 6 mm., double belts a thickness of from 6 mm. to 15 mm.; cotton or camel-hair belts sometimes have a thickness amounting to [illegible] mm.

The speed at which belts may be driven are—

For small dynamos, about 8 m. to 10 m.
,, medium-sized dynamos, about 12 m. to 16 m.
,, large dynamos, about 20 m.

American makers, however, admit a speed of 25 m. and more.

It is not advisable to calculate the diameter of the pulley from the speed and thickness of the driving belt. This method of procedure is wrong, because the ordinary formulæ take no account of the slipping of the belt. It is preferable to calculate the pulley from previous practical experience, and for this purpose the following empirical formula may be used:

$$b = c\,\frac{\text{H.P.}}{v} \quad \ldots \ldots \ldots \quad (119)$$

Table XIII., which will be found at the end of this book, gives the mean values of c: this table has been constructed from figures furnished by seven well-known dynamo firms (Thomson - Houston, J. Farcot, Westinghouse, Crocker-Wheeler, Oerlikon, Ganz and Co., Schuckert). As far as concerns the last number in that table, it may be observed that it applies to a steam-engine driving a sufficiently large transmission pulley. On the other hand, for dynamos it is not advisable to go below a minimum value of $c = 5$.

For machines whose output is less than 400 h.p., the numbers in the table could be expressed in an approximate manner by the formulæ:

$$c = 18\sqrt{\frac{v}{\text{H.P.}}} \quad \ldots \ldots \quad (120)$$

or,

$$b = 18\sqrt{\frac{\text{H.P.}}{v}} \quad \ldots \ldots \quad (121)$$

whence,

$$g = \frac{1}{\gamma}\,18\sqrt{\frac{\text{H.P.}}{v}} \quad \ldots \ldots \quad (122)$$

as a *minimum* thickness for hide belts.

In the United States transmission by belts is much more extensively practised than in Europe, and the breadth of the belts often attains the dimensions of 2·1 m. We can hardly endorse this procedure, since belts of this class are relatively dearer, without taking account of the fact that the working of the dynamos is much less secure. In the generating works of one of the largest electric tramway companies in the United States—that of the Atlantic Avenue Railroad Company, at Brooklyn—an accident which happened some years ago obliged that company to replace each of the large belts by two of half the size, placed side by side. We should avoid as much as possible the use of guide pulleys for belts, as the "life" of the belts is always very much diminished by their employment. We know one installation (generating works for lighting the Secteur of the Champs Elysées, at Paris) where the belts have required repair every 15 days. The distance between two pulleys was only, in this case, about 3·5 m.

In machines where $\frac{\text{H.P.}}{v} > 6$ to 10, use is generally made of hemp cables for the transmission of power.

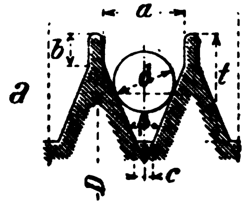


FIG. 179.

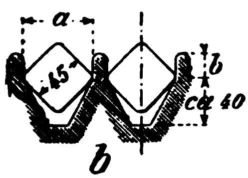


FIG. 180.

For round cables, we have the formula

$$d^2 m = \gamma \frac{\text{H.P.}}{v} \quad . \quad . \quad . \quad . \quad . \quad (123)$$

where m is the number of hemp cables;

d, the diameter of each cable, in centimetres;

γ, a constant varying from 10 to 23.

To give an idea of the latitude which must be allowed to the engineer who studies transmission by means of cables,

we will cite the case related by Mr. Tremlett Carter, in which γ varied from [illegible] to [illegible]. The dynamos of Alioth, of Basle, have dimensions for which γ = 11·5 to 13: the cables of the Oerlikon workshops have a constant γ which is equal, on an average, to 11; and lastly, M. Seiffert gives values for γ varying from [illegible] to [illegible] ("Hülfsbuch für Elektrotechnik," by Grawinkel and Strecker, second edition).

[illegible] Grooved Pulleys Made at the Oerlikon Works.

[illegible]	[illegible]	[illegible]	D mm.	d mm.	n	[illegible]	Admissible Tension in kg. per sq. cm.	[illegible]	Dimensions of Grooves a	b	c	
[illegible]	[illegible]	[illegible]	[illegible]	5	12	27·5	7	12·5	45	5·5	9·15	2
[illegible]	[illegible]	[illegible]	[illegible]	5	14	30	4·4	[illegible]	40	5·5	9·5	1·7
[illegible]	[illegible]	[illegible]	[illegible]	5	9	[illegible]	4·75	[illegible]	45	5·5	5·7	1·8
[illegible]	[illegible]	[illegible]	[illegible]	5	[illegible]	30	4·3	15·4	40	5·5	9·5	1·7
[illegible]	[illegible]	[illegible]	[illegible]	4	6	27·5	[illegible]	[illegible]	45	5·3	9·5	1·4
9·2	[illegible]	[illegible]	[illegible]	4	[illegible]	17·2	[illegible]	10·0	45	5·9	—	—
6·25	[illegible]	21	[illegible]	4·5	5	[illegible]	5·3	12·0	40	5·5	5·4	2·5
6·2	[illegible]	22·[illegible]	[illegible]	4·5	6	24	4·8	15·3	48	5·0	6·5	2·5
[illegible]	[illegible]	[illegible]	[illegible]	4	[illegible]	[illegible]	4·[illegible]	18·4	45	4·8	5·8	1·6
[illegible]	[illegible]	21·7	[illegible]	4·5	6	[illegible]	4·4	10·8	48	5·0	6·5	2·5
[illegible]	[illegible]	[illegible]	75	4	[illegible]	[illegible]	5·4	[illegible]	45	5·1	6·5	1·8
[illegible]	[illegible]	[illegible]	[illegible]	5	4	[illegible]	4·7	[illegible]	45	5·4	6·2	1·8
[illegible]	[illegible]	[illegible]	[illegible]	3·5	6	[illegible]	4·3	17·5	45	3·0	4·0	—

It may perhaps be found surprising that pulleys made in the workshop should present so much difference: but it must be observed that nearly all the grooved pulleys had been made to order in accordance with special instructions from turbine manufacturers.

During several years hemp cables with rectangular sections, after the patent of M. J. H. Beck, of Schaffhouse (Fig. 180), have been employed, and have been found to present the following advantages: (1) these cables cannot turn in the pulley grooves, so that the wear is reduced; (2) the method used in the making of these cables permits of their being woven, whilst quite dry, in such a manner that no subsequent extension takes place.

The catalogue of the previously-mentioned firm contains the following information in relation to the power which may be transmitted by the aid of cables of 45 mm.

NUMBER OF CABLES.

Horse-Power.	Speed of Cable in Metres per Second.			
	12	15	18	20
10	1	1	—	—
20	1	1	1	—
50	2	2	2	2
80	3	3	2	2
100	4	3	3	2
150	5	4	3	3
200	7	6	5	4
250	9	8	6	5
300	10	9	7	6
400	14	11	9	8
500	16	14	11	10

4. *Armature Core and Spider.*

The *insulation of the iron discs* is effected, sometimes by the interposition of sheets of paper of thickness varying from 0·04 mm. to 0·06 mm., sometimes by the use of a layer of varnish covering the iron discs, and, finally, by the use of discs whose surfaces are oxidised. This latter method is employed, for example, by the Edison Company, at Schenectady, N.Y. It is difficult to believe that it is less costly than that in which sheets of paper are used.

A certain number of firms employ special machines, furnished with elastic rollers, for the purpose of spreading the varnish more uniformly over the discs.

A rational method of insulation consists in sticking the sheets of paper to the discs by means of gum lac before the notches are punched out. In this manner the layers of paper are punched at the same time as the discs, and, which is more important, the armature forms, so to speak, a block of iron whose shape is hardly modified after it has left the hydraulic press. In the method of which we speak the wrought-iron discs should be heated whilst in the press; after two or three hours the discs adhere together in a durable manner.

Since the thickness of the discs generally employed amounts to from 0·5 mm. to 0·6 mm., from 85 to 90 per cent. of the total section is utilised, taking account of the roughness of the discs.

The discs for *toothed armatures* are either punched before they have been joined together, or milled out afterwards; it is not possible to punch them after the discs have been built up, for it might happen that one or more teeth would be torn off. In all cases the notches should be carefully filed to prevent contact between the iron discs at their line of junction. The author has remarked on several occasions that heating of the teeth was solely due to contacts between the discs, and that it was entirely removed after the notches had been carefully freed from burrs. In a particular case the heating was increased after a filing which had not been performed with sufficient care. This shows that this operation must be most conscientiously performed in order that the desired end may be attained.

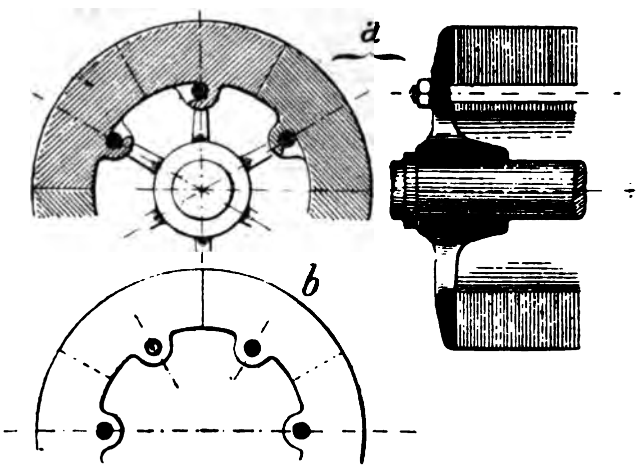


Fig. 181.

The iron discs, which are arranged one on each side of the armature, are generally made of wrought iron of from 2 mm. to 3 mm. thickness. Armatures formed from windings of iron wire appear to have been abandoned for reasons which may easily be conceived.

In *dynamos with lateral poles* the armature is formed from windings of iron ribbon, with layers of paper interposed. For the rest, this type is less generally used at the present time than it was formerly, perhaps, in part, because the iron ribbon

is more costly than the discs, and cannot be obtained in sufficient lengths.

Discs in one piece can only be obtained when the diameter of the armature is not greater than from 1 m. to 1·2 m.

For armatures larger than this it becomes necessary to cut the discs in several segments. The reunion of these segments is effected in several different manners, as shown in Figs. 181 and 182, which can be understood without further description.

181*a* is due to Wood, of Cleveland.
181*b* „ G. Kapp.
182*a* „ the Oerlikon Works.

FIG. 182.

Concerning the manner in which these iron discs are mechanically connected to the shaft, we will only mention a number of typical methods, the space at our command being insufficient to allow of a description of other forms derived from these, and differing from them only in details of little importance.

In the case of the armature represented in Fig. 183 (Electricitäts Actien-Gesellschaft, formerly Lahmeyer & Co.), which shows a disposition often employed for small armatures, the discs are placed directly on the shaft, and held in position by

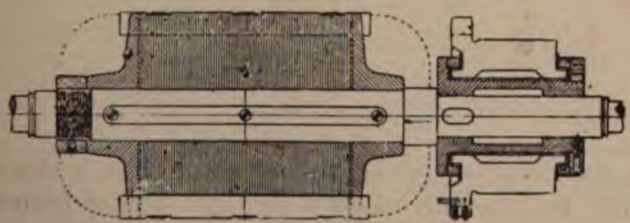


FIG. 183.

means of a nut. This arrangement is perhaps less rational in the case of a motor than in that of a generator. Indeed, in the case of dynamos of this class, constructed in great numbers and kept in stock in order to diminish their net cost, it is not easy to alter the shafts, which in many cases must be

done in the case of motors. This inconvenience is avoided in the types of armatures shown in Figs. 184 and 185, since the shaft could in these cases be changed, even when the winding has been completed.

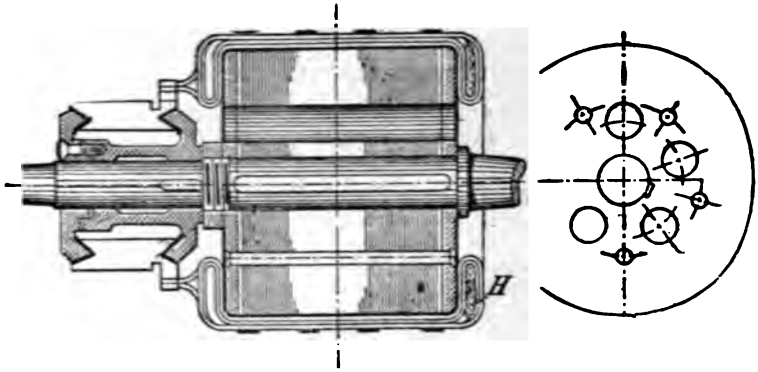


FIG. 184.

In particular the arrangement shown in Fig. 184 presents many advantages: the principle was first employed by the Westinghouse Company, of Pittsburgh, who constructed even powerful alternators after the same type. Its principal advantage consists in rendering a special supporting framework for the armature unnecessary.

It is true that this arrangement entails a great deal of loss in the discs, but this loss is sufficiently compensated for by the suppression o the armature spider. For dynamos of average output the Oerlikon Company make use of an arrangement represented in Fig. 186. The armature spiders are each formed of six spokes with six projecting keys, which fit into recesses in the armature discs. The projecting keys are alternately long and

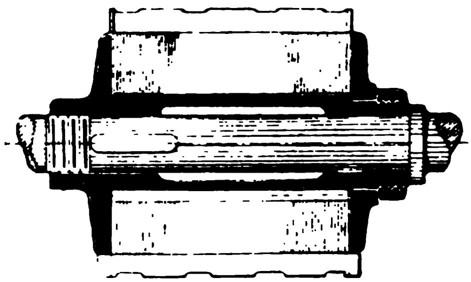


FIG. 185.

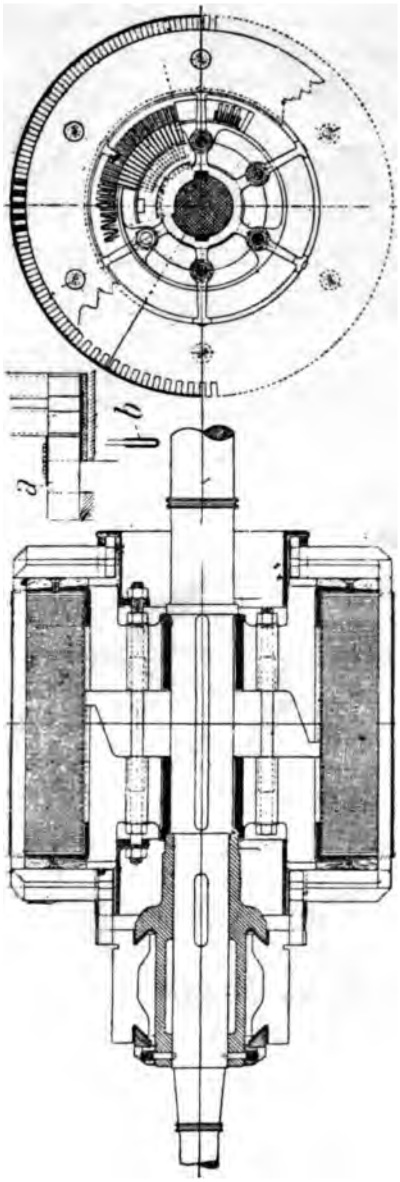
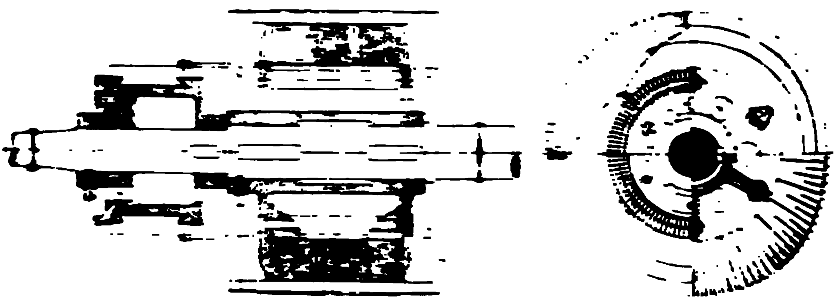


FIG. 186.—Armature for medium output. Oerlikon system.

[illegible] corresponding to the short [illegible]

[illegible] characteristic forms of [illegible] General Electric [illegible] basis.



[illegible] the armature repre- [illegible] the extreme discs are in [illegible] The armature Fig. [illegible] is further

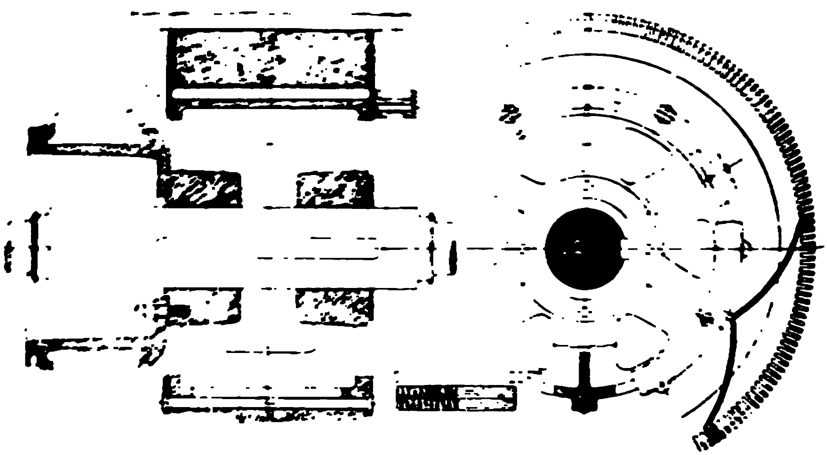


Fig. [illegible]

furnished with an artificial ventilation which is obtained by the interposition of two brass discs carrying ribs. It is, however, very doubtful whether this ventilation is of any real utility.

We now arrive at the consideration of armatures of which the windings are disposed along the periphery.

Fig. 189: tramway generator (H. F. Parshall), General Electric Company.

Fig. 190: four-pole dynamo by Brown, Boveri, and Co.

The first of these dynamos is also furnished with an artificial ventilation for the body of the armature. This dynamo presents a further interest, inasmuch as the insulation of the commutator sections is effected in a manner both complete and original.

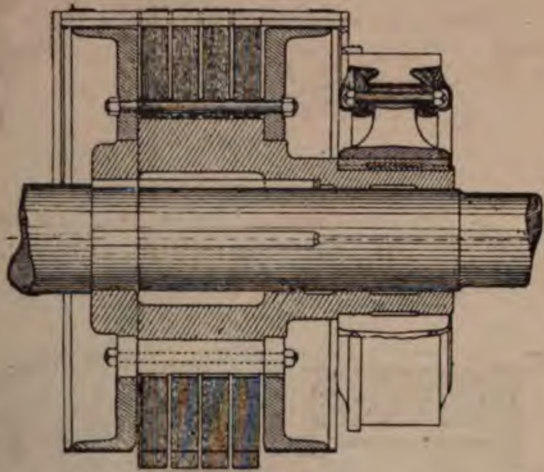


FIG. 189.

As, moreover, the discs are furnished with ears which engage with the cast-iron spokes of the armature spider, driving horns may be dispensed with.

In the armature of Brown's multipolar dynamos the bolts which clamp the disc together serve at the same time to transmit the driving force; for this purpose they are buried half in the cast-iron body and half in the wrought-iron discs.

Most of the figures given up to the present refer to drum-wound armatures.

Lastly, we will mention five arrangements specially adapted for ring armatures (Figs. 191-196). (Other well-executed cuts representing armatures of different forms may be found in the previously-mentioned work of M. Arnold.) With the exception

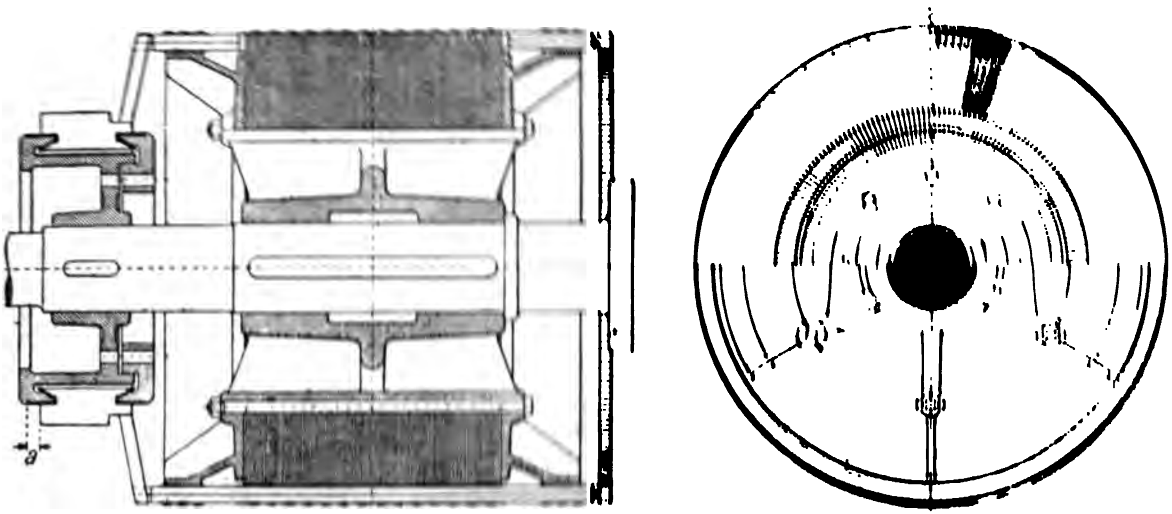


Fig. 190. Armature of a Dynamo. Brown, Boveri, and Co., Baden (Switzerland).

of Figs. 194 and 195, these are equally well adapted for use with drum-wound armatures. A very simple arrangement, which is at the same time very cheaply constructed, has been designed by the author and manufactured by the house of Farcot at Saint-Ouen (Figs. 192 and 193). These figures refer to a dynamo of 250 h.p. and 360 revolutions per minute. In order to facilitate the compression of the discs in the hydraulic press, a length greater by several centimetres than that absolutely necessary is given to the bolts, which thus serve as guides for the discs; they are cut, after compression has taken place, to the exact length required.

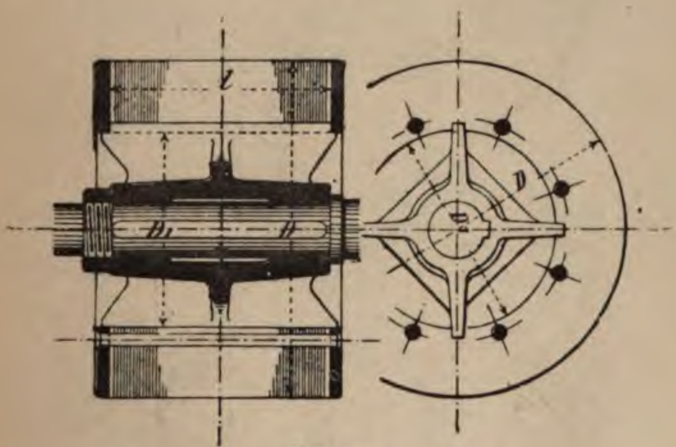


FIG. 191.

It is hardly necessary to remark that these bolts need not be insulated, and that it is not necessary that they should be made of brass or bronze. It is even permissible to allow these bolts to penetrate deeply enough into the iron body of the armature without our having cause to fear excessive heating, since their self-induction is so considerable, owing to the feeble saturation of the iron, that strong currents cannot be produced. A complete view of this machine is given in Chapter IX.

In the types already described, as well as in the two following ones (Figs. 194 and 195), the spokes drive the armature core, being for this purpose inserted in the wrought-iron discs.

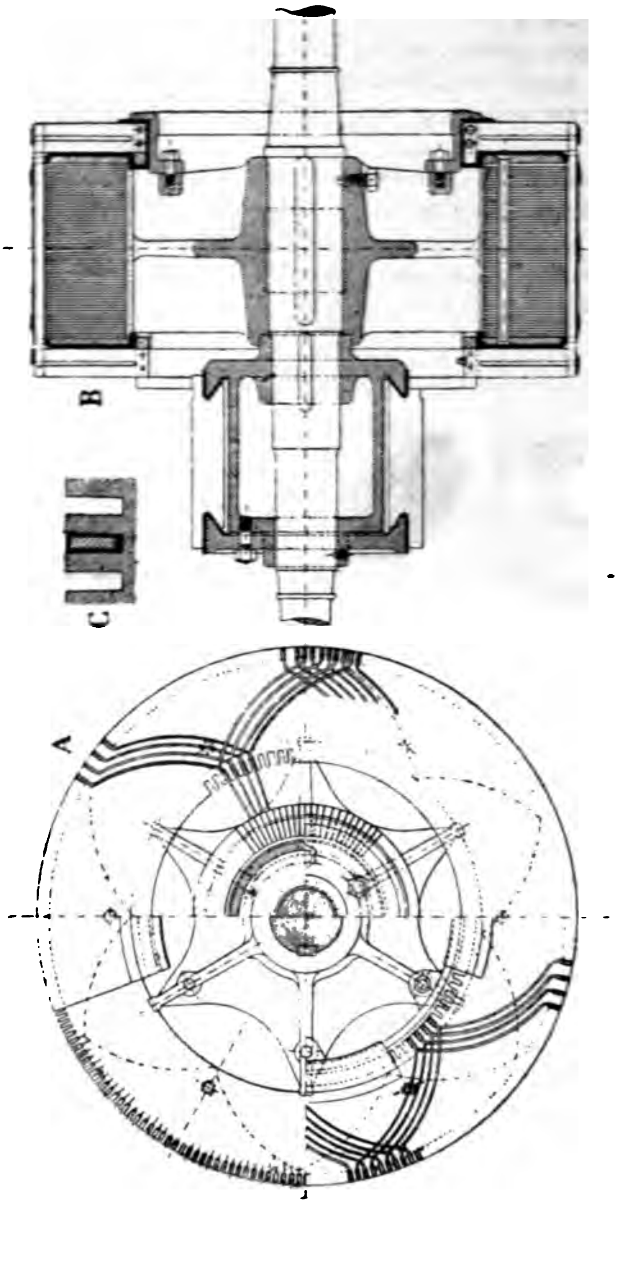


FIG. 192.—Armature of a 170-kw. Dynamo, designed by the Author and made by J. Farcot, Saint-Ouen.

On the other hand, in the machine (Fig. 196) use is made of small keys which engage half in the armature spider and half in the discs.

As we have already stated, the spider of a ring armature should be made of bronze. In the case of a drum-wound armature, cast iron is generally used in order to diminish the cost.

As a general rule, powerful dynamos are furnished with a drum winding, or, when a ring winding is adopted, the spider is in two pieces, the hub and the spokes in cast iron, whilst the rim is in bronze (see the arrangement of M. Thury, Chapter IX.)

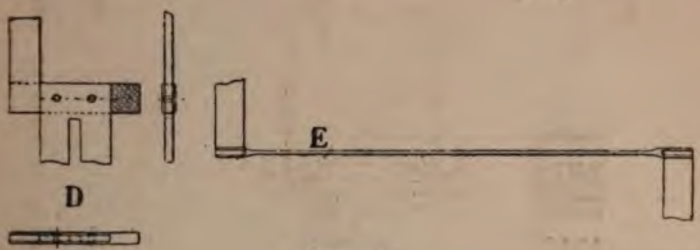
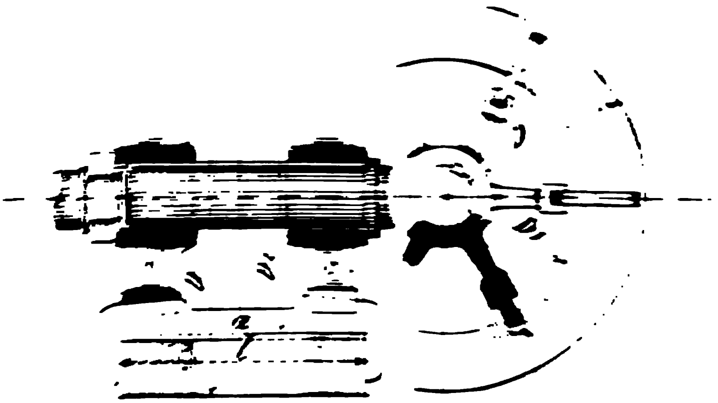


FIG. 193.

We believe that it can be shown, by citing some numbers, that the old prejudice in favour of the necessity of careful insulation for the bolts is really unfounded (see Schweiz, *Blätter für Electrotechnik*, February, 1898). The exceptional cases where an excessive heating has been observed occurred in bipolar machines in which the cores were strongly saturated. On the other hand, in multipolar machines, where, in order to avoid hysteresis losses, a very feeble saturation is employed, the insulation of the bolts is practically useless. Since any currents produced in the bolts will be alternating, it is easy to explain the reason of this. We will take for the basis of our calculations the most unfavourable case in which the bolt passes through the midst of the iron core. This is practically the case in the dynamos of Siemens and Halske and of Schuckert. When the armature revolves, the lines of force circulate round the bolts and their sense changes every time that a bolt passes by the axis of the poles. The flux is greatest when the bolt is in the neighbourhood of the neutral

[illegible] Let [illegible] represent the maximum number of lines, $\omega =$ [illegible] the periodicity, and [illegible] a coefficient whose absolute value is not required in the calculation.



[illegible]

The mean E.M.F. along the bolt is then

$$E = [illegible]$$

[illegible] number of bolts is equal to the number of poles, each couple of bolts will form a closed circuit. An alternating

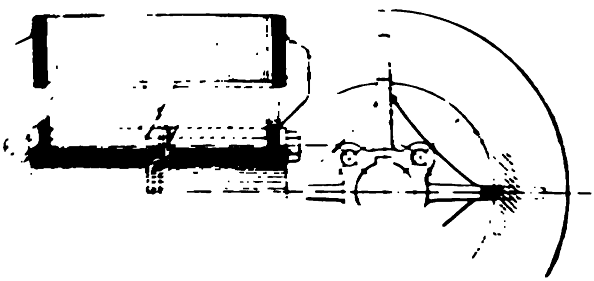


Fig. 195.

current will therefore be produced whose periodic curve will resemble that of the E.M.F. This current will engender, in its turn, lines of force which will also surround the bolts, the

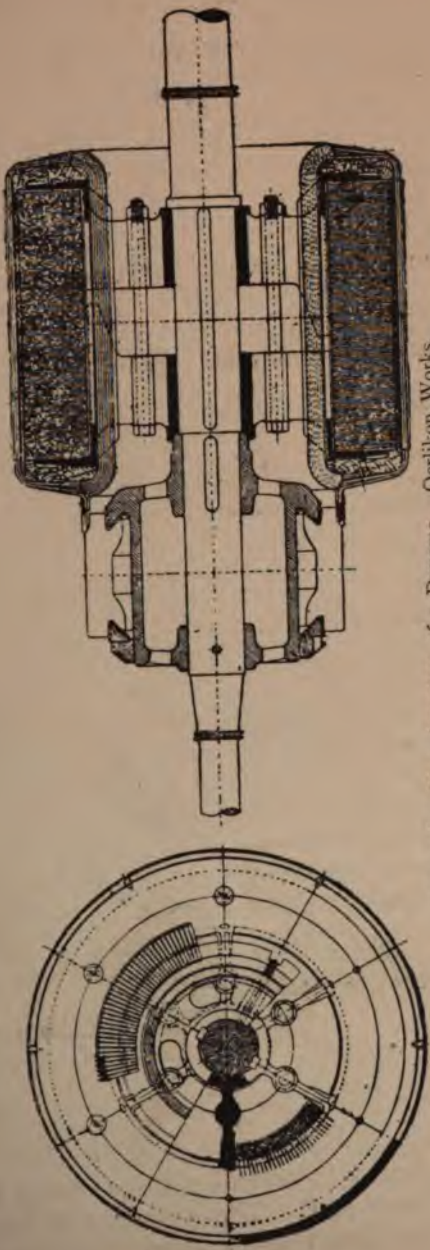


FIG. 196.—Ring Armature of a Dynamo. Oerlikon Works.

number of lines being proportional at any instant to the current flowing in the bolts. We will designate the maximum strength of this secondary field by $\overline{\phi}$.

But we know, in accordance with the laws developed at the commencement of this book, that a variable field circulating around a conductor produces in the latter an E.M.F. which will have the same value, whether the variation is produced by the motion of the conductor in a field of constant strength, or whether, the conductor remaining stationary with regard to the field, the latter is modified in an equivalent manner. When the field is produced alone by the current in the conductor, the E.M.F. thus induced is called *the E.M.F. of self-induction*. We can determine this in a manner analogous to that used above.

We therefore have

$$E_s = \omega \kappa' \overline{\phi} \, 10^{-8}.$$

When the resistance of the conductor may be neglected in comparison with the self-induction we shall have

$$E_s = E;$$

and as, moreover, κ' could be taken approximately equal to κ, we shall have

$$\overline{\phi} = \overline{\Phi}.$$

In this equation Φ is known beforehand; moreover, $\overline{\phi}$ is a function of the current strength, C; we could therefore determine the current strength by the aid of the equation as soon as the relation between $\overline{\phi}$ and C can be expressed.

Let us consider a magnetic circuit of length L acted on by C N ampere-turns; the density of the lines of force is determined approximately by the empirical formula

$$B = 21{,}500 - \frac{19{,}600}{\sqrt[3]{H}} \quad . \quad . \quad . \quad . \quad . \quad (124)$$

in which $$H = \frac{4\pi}{10} \frac{C\,N}{L}.$$

In this way the following table has been constructed, the values, which were obtained by the use of the above formula, differing by no more than 1 or 2 per cent. from those found from the curve for wrought iron given at the end of this

volume. The agreement is noticeably good between the limits of 4,500 and 18,400 lines.

H.	B (from curve).	B (calculated).	Error.
1·5	4,500	4,400	− 2 per cent.
2	6,000	6,000	0 ,,
5	10,000	10,100	+ 1·0 ,,
10	12,300	12,400	+ 0·8 ,,
30	15,400	15,200	− 1·3 ,,
70	17,000	16,750	− 1·2 ,,
140	18,000	17,730	− 1·5 ,,
300	18,400	18,580	+ 1·0 ,,

For other curves of wrought iron it will suffice to alter slightly the constants in the foregoing equation.

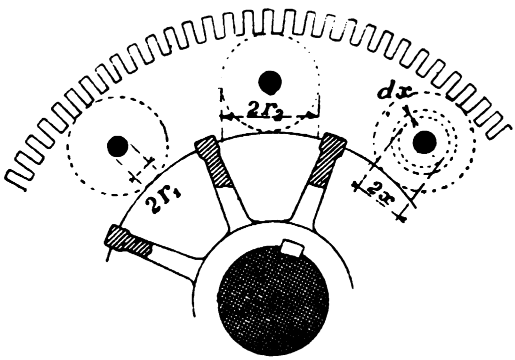


FIG. 197.

We will now make a supposition the most unfavourable for our demonstration—*i.e.*, that the lines of force only circulate in the interior of a circle having for diameter the difference between the external and internal radii of the discs; then in supposing that the maximum current strength is C and that N = 1, the total number of lines will be

$$\bar{\phi} = l \times \int_{r_1}^{r_2} \left(21{,}500 - \frac{19{,}600}{\sqrt[3]{\frac{4\,\pi}{10} \; \frac{C}{2\,\pi\,x}}} \right) d\,x \qquad (125)$$

$$= l \left[21{,}500\,(r_2 - r_1) - \frac{25{,}000}{\sqrt[3]{C}} \left(r_2^{\frac{2}{3}} - r_1^{\frac{2}{3}} \right) \right];$$

or, in general, $$\bar{\Phi} = l\left[\alpha - \frac{\beta}{\sqrt{\bar{C}}}\right] \quad . \quad . \quad . \quad . \quad (126)$$

The values of α and β will be found in the table, p. 295.

Let us suppose that the current may be expressed by means of a sine curve: then the maximum current will be $= \sqrt{2} \times C$, and, as a consequence,

$$\bar{\Phi} = \sqrt{2} \times \Phi.$$

Hence the mean current strength will be

$$C = \frac{1}{\sqrt{2}}\left(\frac{\beta l}{\alpha l - \Phi}\right) \quad . \quad . \quad . \quad . \quad (127)$$

We will here work out a numerical example:

Let us suppose that the data furnished respecting a six-pole dynamo, of 180 kw., is as follows:

Arc of the pole-pieces = 44 cm.

Saturation = 7,000.

r_1 = 5 cm.

r_2 = 1 cm.

Number of bolts = 6.

Resistance of a bolt, considered as a complete circuit, 0·00016 ω.

From the table, p. 295, we obtain

$$\alpha = 172,000 ; \qquad \beta = 445,000.$$

We further have

$$\Phi = \tfrac{1}{4} \times 44 \times 7,000\, l = 77,000 \times l.$$

Hence,

$$C = \left(\frac{445,000 \times l}{172,000 \times l - 77,000 \times l}\right)\frac{1}{\sqrt{2}} = 74 \text{ amperes.}$$

The loss in watts in the bolts is therefore equal to

$$6 \times 0·00016 \times 74^2 = 5·2 \text{ watts.}$$

This calculation shows that no advantage will be gained by insulating the bolts of this machine.

5. *Commutator and Winding.*

Commutator.—In small dynamos we often meet with arrangements in which the commutator is built up on the armature

TABLE OF VALUES OF α AND β.

r_1		Values of r_2.								
	2·5	3	3·5	4	5	6	7	8	9	10
0·5 { α =	43,000	53,800	64,500	75,300	98,000	118,000	140,000	—	—	—
0·5 { β =	75,000	98,500	123 000	149,000	204,000	263,000	325,000	—	—	—
0·75 { α =	—	48,900	59 000	70 000	91,500	113 000	134,000	156 000	—	—
0·75 { β =	—	91.400	116.000	142 000	197,000	256,000	318,000	386,000	—	—
1 { α =	—	—	—	64,500	86,000	107,500	129,000	150,000	172,000	—
1 { β =	—	—	—	134,000	188,000	247,000	310,000	376,000	445,000	—
1·25 { α =	—	—	—	—	80,600	102,000	129.000	145,000	145,000	188,000
1·25 { β =	—	—	—	—	180,000	239,000	301,000	370,000	370,000	506,000

shaft. This method of construction is not a rational one, since the replacement of a commutator so constructed when worn out is practically impossible. For this reason all modern dynamos are fitted with removable commutators.

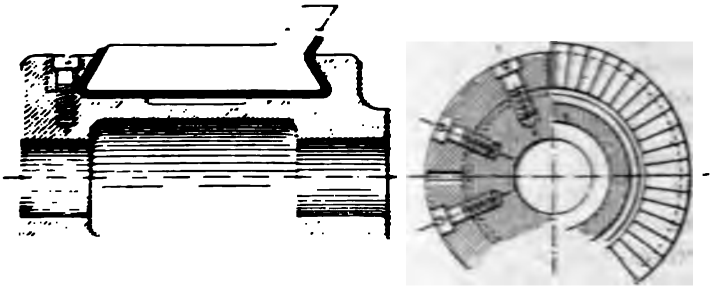


FIG. 198.

Typical forms of commutator have already been passed in review when considering the armature: two new arrangements are shown in Figs. 198 (Siemens and Halske) and 199 (Schuckert). These two forms differ in having the clamping ring composed of several pieces which are bolted together. The commutator (Fig. 198) presents the advantage that its sections can be clamped and adjusted before mounting on the commutator case.

In dynamos where the commutator sections are held in position by a nut, this latter should not press directly on the sections or on their insulation; it is necessary to interpose a washer, since without this precaution the insulation will be injured whilst the nut is being screwed up. In this case it is also well to use a nut of small pitch in order to prevent its accidental loosening: a lock-nut or a locking screw may be used, and this latter may be further utilised to prevent lateral motion of the commutator case on the shaft (Figs. 183 and 186).

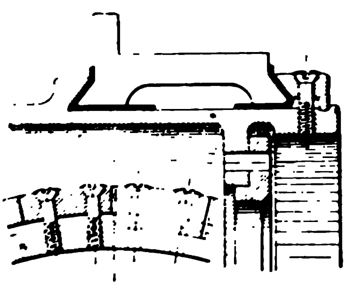


FIG. 199.

To insulate the commutator sections one from another,

Indian mica (Canadian mica, though cheaper, is not well adapted for this purpose on account of its stiffness), compressed card, vulcanised fibre, or amianthus, may be used. The two latter substances cannot be employed except when the dynamo is to be employed in a dry place. To insulate the conical surfaces the use of *compressed card* (Presspahn) or of *micanite* may be recommended. We can procure pieces already shaped for this purpose either in *micanite*, which is made from pieces of mica stuck together with gum lac or copal varnish, or in *compressed card* (Presspahn).

During several years micanite has been used to insulate the commutator sections one from another. However, this latter method exacts great precaution in its use in order that the commutator may not wear unequally or become deformed after some time of working. In order to prevent the latter possibilities, heat is applied whilst the clamping is being finished. Micanite presents the great advantage, in comparison with pure mica, that it is cheaper and may be made into sheets of considerable size. In small machines of less than 10 h.p. the difference in price is small, and pure mica should be used.

The insulation of the commutator sections from the case should be performed with great care. For this purpose the insulating layer should extend beyond the ends of the commutator sections, at any rate in high-voltage machines, for a distance, a, of from 5 mm. to 10 mm. (Fig. 190). An insulation of this sort is realised with great success in the Parshall tramway generators, which have been previously considered (Fig. 189).

To diminish the number of brushes, opposite commutator sections are sometimes united by means of cross-connections (p. 22). But these cross-connections should not be placed in the interior of the commutator; preference may be given to the arrangement shown in Fig. 200.

The angle α at which the ends of the commutator sections are inclined with respect to the axis, varies between $40°$ and $50°$; the angle which is at once the most rational and the best adapted for purposes of design in $45°$. In consequence of this oblique form the case sustains a tractive force when the armature is revolving, and the component of this force

parallel to the axis may be easily found (in kilogrammes) from the following formula:

$$Z = \frac{\tan \alpha}{2} \frac{G}{9\cdot81} \frac{v^2}{r} 100. \quad . \quad . \quad . \quad (128)$$

in which we designate by

G the weight of the commutator segments (in kilogrammes);
v the linear velocity of the centre of gravity of each section, in metres per second;
r the radial distance of the centre of gravity of each section from the axis of revolution.

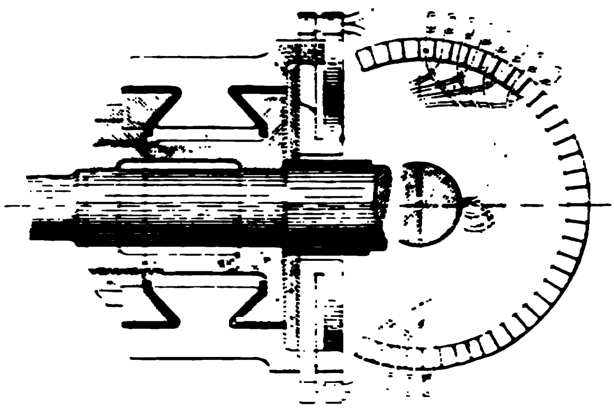


FIG. 200.

Commutators tend to break at the point c (Fig. 201), and these ruptures are generally due to faults in the cast iron. For this reason, and for greater security, the portion hatched in the figure should be cast in one piece with the body, b, and the necessary conical groove turned out afterwards. It is the same with the spider of the armature (Fig. 202, c).

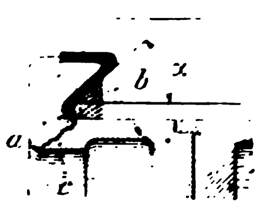


FIG. 201.

We will now consider the special rules to be followed in the construction of commutators:

(a) For the construction of the commutator sections, when copper brushes are employed, we may use hard bronze with

an insulation by means of compressed card (Presspahn) or mica. When carbon or brass brushes are employed, hard hammered copper with mica insulation should be used. In the United States the segments are generally forged in special moulds.

(*b*) In high-pressure series-wound machines the difference of potential between two contiguous sections should be

$$e_2 = \frac{E\,2\,p}{N_2} < 30 \text{ volts.}$$

(*c*) The insulation between two sections should have—

For a pressure up to	250 volts,	a thickness of	0·5 to 0·6 mm.
,, ,,	500 ,,	,,	0·7 to 0·8 ,,
,, ,,	1,000 ,,	,,	0·8 to 1 ,,
,, ,,	2,000 ,,	,,	1 to 1·2 ,,

(*d*) The necessary length of the commutator depends on the area of the surface of the brush by means of which electrical connection is established; this should not be confounded with the section of a brush. For metallic brushes an area of 4 square millimetres per ampere is generally allowed; but this area is often much larger in small machines. For well-made machines, we have

Surface of contact (in square millimetres)

$$= 5 + \frac{200}{\text{amperes per line of brushes}} \quad . \quad . \quad (129)$$

For carbon brushes we may allow a minimum area of 13 to 15 square millimetres per ampere; when the space is not too much restricted we may even allow from 20 to 25 square millimetres.

(*e*) The commutator should be so constructed as to avoid any risk of its rupture through the centrifugal force (see also the recommendations, p. 315).

Winding.—Ring windings are almost exclusively employed on smooth armatures. Fig. 202 gives some details of the arrangement adopted by the Oerlikon Company. Instead of wooden discs, other insulators are used, such as cloth, micanite, paper, isolite, etc., which present the advantage of occupying less space, whilst effecting an equally good insulation.

To obtain a rational winding in which the extremities of the wires project, the winding of each section should be, when possible, commenced at the middle of the wire.

Drum windings are much the most numerous; we can class them in three groups: (1) Windings *en chignon* (Fig. 183); (2) regular windings, with cross-connections at the base of the drum (Figs. 184, 186 to 188, and 192); (3) windings having cross-connections on the cylindrical surfaces.

The first method is used only in small dynamos, wound with wires, but it requires a very good insulation in the conductors which cross each other. In the case of the regular windings with cross-connections at the bases, we may adopt several arrangements. Thus we can, following the example of the General Electric Company, employ for the cross-connections straight bars which have been curved by the aid of special pincers.

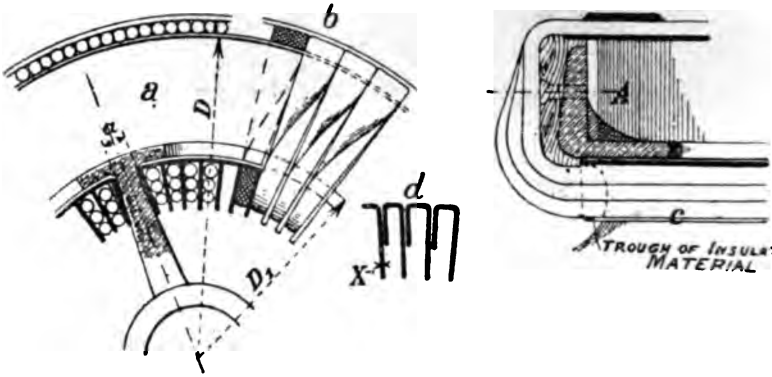


FIG. 202.

This method (Fig. 187) has been used for a long time at the Oerlikon Works, with this difference, that it is not the cross-connections but the *longitudinal bar* which is bent at its two extremities in such a manner that each of the latter forms a handle of the junction forks (see also the arrangement designed by the author, Figs. 192 and 193). The reunion of the two forks is obtained by means of a copper gutter, in which the two extremities are soldered. These gutters must be connected, in their turn, with the commutator by means of a special copper bar, which can be

soldered separately for repairs. A perfection is thus ...lised that is not to be disdained.

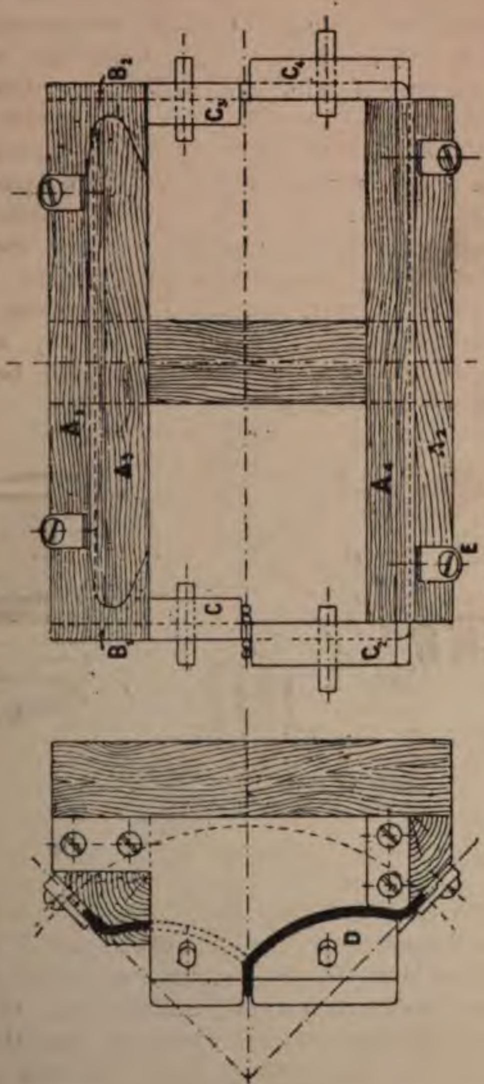


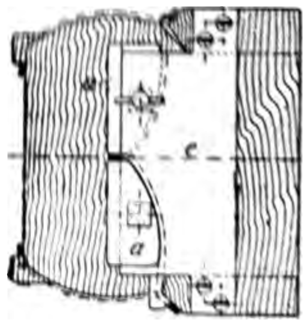
Fig. 203.

Fig. 188 shows an armature of a tramway generator, due ... Alioth, of Basle, in which the two forks form one piece. ...e windings, arranged along the cylindrical surface of the

armature, are very simple as to their manufacture: they were, as far as we know, first made by Mr. C. E. L. Brown (1892).

As is shown in Figs. 189 and 190, the special forks are done away with in this case. The principal inconvenience in these windings depends on their considerable length along the axis, above all in the case of a machine with a small number of poles.

If the space reserved for the windings is sufficient, these latter may be regularly shaped from wire by the aid of a former (Figs. 203 to 206), introduced for the first time by M. Alioth, of Basle (1885), and by Mr. Eickemeyer, at Yonkers (N.Y.), in 1888. A former of this kind, for machines of two or four poles, with parallel windings, is represented



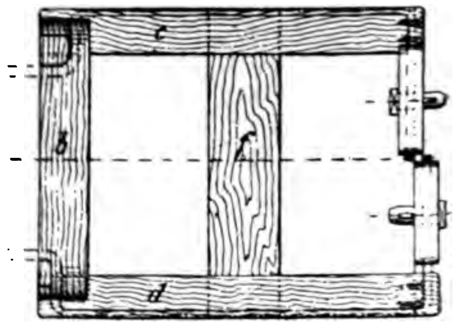


FIG. 204.

in Fig. 203. It is composed of two pieces of wood, A_1 and A_2, with guide pieces, A_3 and A_4, which are maintained in position by means of iron plates, B_1 and B_2, and by a wooden strut in the middle. On the iron plate are placed the removable templates, C_1, C_2, C_3, and C_4.

The wire is bent on the plates and engaged under the templates, C, after which it is placed along the guides, A_3 and A_4. The bolts, E, serve to fix the wire. To remove the winding when finished, it is only necessary to remove the templates, C.

Fig. 204 represents a former for series winding; the wire is shown by the dotted lines. In most cases we do not attempt to finally shape the winding in this manner, but we bend the lateral wires connected to the commutator by hand—or rather,

hat which is certainly preferable, we wind only the right-hand nd wire on the former, so that a single branch of the fork s formed on each side and the second layer is executed by hand on the armature (Fig. 184).

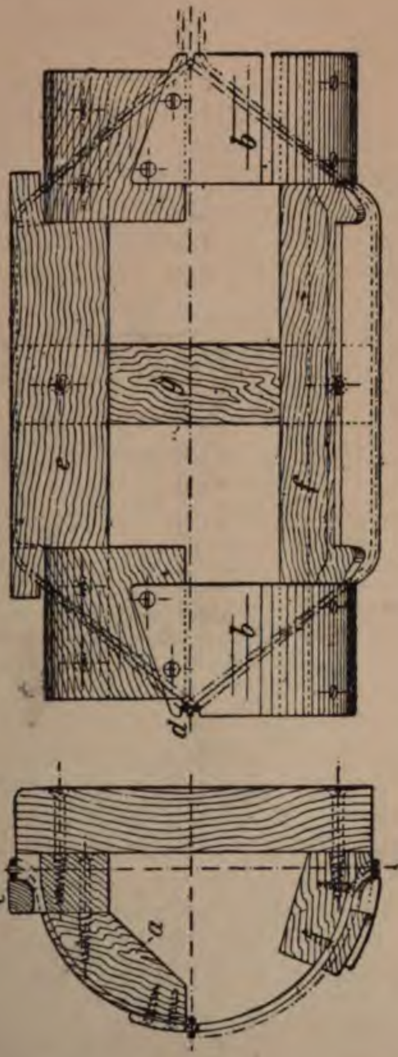


FIG. 205.

The labour in performing this could be diminished by the interposition of a wooden disc, H (Fig. 184).

The former shown in Fig. 205 is destined to shape the windings to be placed along the cylindrical surface of an armature, and has been employed by the author for a bipolar dynamo represented by Fig. 240 *a* and *c*. The special point in this winding consists in the distribution of the wires of an armature section in two slots, so as to diminish the self-induction.

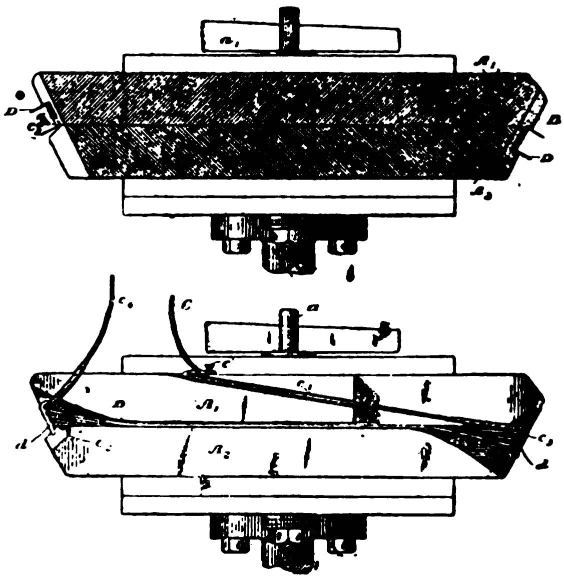


FIG. 206.

Figs. 206 and 207 show the process of manufacture of the windings for tramway motors by the Westinghouse Company. This winding forms a mean between a winding *en chignon* and a regular winding. Each coil is additionally insulated by means of a ribbon.

The great advantage gained by the use of a former for winding is due both to its small cost and the rapidity with which the work can be carried out. Thus it is stated that a motor for the tramways of the Westinghouse Company, of 30 h.p. (95 slots), could be wound in about 15 hours, a time which is in all probability not under-estimated. The author had occasion some years ago to wind the armature of an 80-h.p. dynamo (the bobbins being

already made) in 40 hours, which an experienced winder could doubtlessly have performed in 30 hours.

In the case of drum windings on smooth armatures, it is indispensable to use driving horns—that is to say, projections in brass or in fibre inserted in the armature; the adherence of the wires to the surface of the armature is insufficient to prevent slipping.

FIG. 207.

Insulation of toothed armatures is effected by means of paper, of mica, of micanite, or micanite cloth, etc. We know that in toothed armatures no tractive force is exerted on the windings, which permits of our employing insulators possessing very little mechanical strength. We will give some information as to the capacity to resist piercing by sparking of certain substances submitted to alternating currents; this information is taken from the publications of Mr. Plumb (*Sibley Journal*, June, 1895).

Thickness of Insulation in mm.				Voltage Necessary to Pierce the Insulation.
Oiled Paper.	Mica.	Air.	Layer of Oil.	
—	—	—	0·28	400
—	—	0·76	0·76	2,140
—	—	2·67	1·27	5,190
—	—	3·43	1·90	6,280
—	—	3·94	2·54	6,980
0·466	—	—	—	10,400
—	—	7·26	3·80	11,200
—	—	9·80	5·08	13,300
—	0·216	—	—	16,900
—	—	—	10·30	43,000

Experiments carried out at the Oerlikon Works have given the following results:

Insulating Material.	Thickness mm.	Volts.	Remarks.
Corde Bellé No. 1,779	0·0375	180 to 270	Insulation for armature discs.
Parchment paper (incombustible)	0·0625	720 to 810	—
Insulating paper, 241 (white)	0·11	1,220	—
Celluloid sheet (brown ...	0·10	1,350 to 1,530	Field-magnet windings and body of armature.
Paper doubly oiled ...	—	1,800 to 2,000	Insulation between the wires crossing each other for *chignon* windings.
Micanite paper (two layers of silk paper enclosing a layer of mica)	0·1 to 0·16	2,000 to 2,400	Insulation for slots.

It can be generally assumed that a layer of micanite 0·1 mm. thick can support a pressure of 7,000 volts.

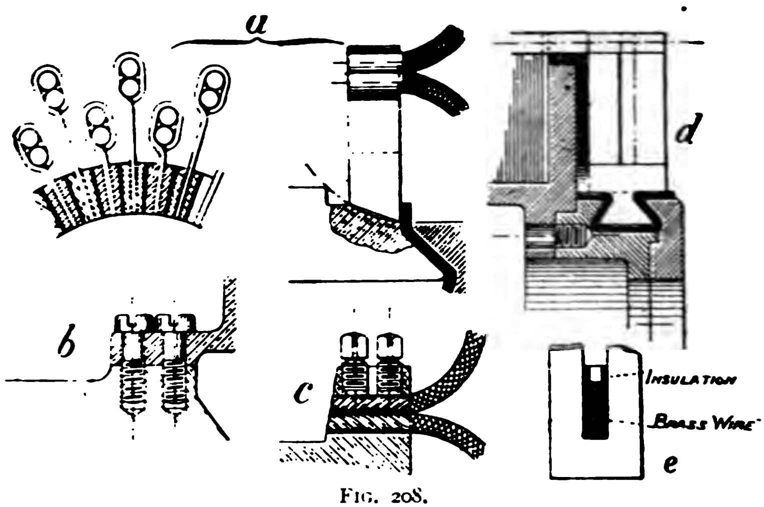


FIG. 208.

The *junction of the winding with the commutator* is effected sometimes with solder, sometimes by means of bolts; the first method is preferable to the second. Reference may be made to the figures already cited, as well as to Fig. 208. When the armature is wound with wires, the most simple

method is to solder these directly to the commutator sections; in cases where this would be impracticable, owing to the thickness of the wires, the arrangement shown in Fig. 208*a* may be followed. This arrangement is also to be recommended when the commutator sections are made of drawn copper, since it corresponds to the smallest possible waste of metal. To protect the windings and to prevent the introduction of dust amongst them, the armature is often furnished with a covering of cloth (see armature, Fig. 227). In the case where carbon brushes are employed, this covering is not necessary. Moreover, it is not rational to place it on that side of the armature next to the pulley; when that is necessary, several holes should be made in the cloth. In fact, it has been observed in several cases that short-circuits have been produced solely by the fact that the moisture deposited in the armature during cooling tends to spread toward its periphery, and damage the insulation there.

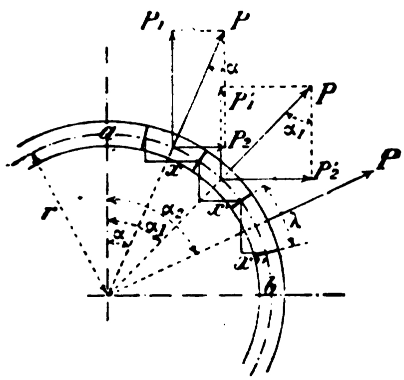


FIG. 209.

6. *Binding Wires and Auxiliary Collectors.*

Binding wires are used to maintain the armature windings in their places against the centrifugal force developed by the revolution of the armature. To determine this latter, we will consider the windings as forming a tube of length L (in centimetres), thickness a (centimetres), and of radius $r = \frac{D}{2}$ (Fig. 209). We will suppose this surface to be cut into infinitely small segments, of length λ, and we will determine the centrifugal force acting on each one of these. We have

$$P = \frac{\text{Mass (in kgrm.)}}{9{\cdot}81} \frac{v^2}{r} 100 = \gamma \, L \, . \, \lambda \, a \frac{v^2}{r} \frac{1}{10} \cdot \frac{1}{9{\cdot}81}$$

(γ being the mean density of the space occupied by windings).

$$P_1 = P \cos a = P \frac{x}{\lambda}.$$

The traction which will be exercised on the section of the binding wire could be deduced from these formulæ; it is $P_1 + P_1' + P_1'' + \ldots$

$$= \gamma \lambda \mathrm{L} a \frac{v^2}{r}\left(\frac{x}{\lambda} + \frac{x'}{\lambda} + \frac{x''}{\lambda} + \ldots\right) \frac{1}{10 \times 9{\cdot}81} = \gamma \frac{\mathrm{L} a v^2}{10 \times 9{\cdot}81}.$$

In this equation, we may replace

a by $\dfrac{\mathrm{N}\,s}{\mathrm{D}\,\pi} \dfrac{1}{100}$,

(s being the section of a wire in square millimetres);

v by $\dfrac{\mathrm{D}\,\pi\,n}{60} \dfrac{1}{100}$,

γ by 9·2 (taking account of the mass of the insulation).

The tractive force exercised on the section of all the binding wires may be taken, for simplicity, as

$$Z = \mathrm{N}\,s\,\mathrm{L}\,\mathrm{D}\,n^2 \frac{0{\cdot}83}{10^{10}} \quad . \quad . \quad . \quad . \quad (130)$$

The most difficult point is to determine the length L, in which we must include only that part which is really under the action of the centrifugal force, and which is not protected by closed notches, or in any other manner.

TABLE OF VALUES FOR THE BREAKING WEIGHT OF WIRES.
After M. Lazare Weiller, the formula of Hutte, etc.

Brass wire	50 kgrm. per sq. mm.
Bronze wire...	46 ,, ,,
Double bronze wire	80 ,, ,,
Durana wire	80 ,, ,,
Delta metal...	100 ,, ,,
Siliceous bronze (type C. Lazare Weiller)	75 to 80 ,, ,,
Drawn copper	45 ,, ,,
Bessemer steel	65 ,, ,,
Crucible steel wire	120 ,, ,,

The formula previously established will suffice to show in what manner the necessary data for the bindings can be calculated. However, in practice little use is made of such formulæ; in fact, electricians appear to have acquired the habit of calculating out the electrical part of a dynamo to the fourth decimal figure, and entirely neglecting calculations respecting the mechanical part. We will see from the following calculations whether this practice can be defended or not.

Example 1.—We will first choose for calculation the case of a dynamo of 300 h.p., with a moderate peripheral speed, and a toothed armature.

Let $n = 300$; $L = 60$ cm.; $N = 490$;
$s = 30$ sq. mm.; $D = 115$ cm.

We will suppose that the wires are maintained in position at the two ends of the armature, which, however, is not always the case in reality; hence L is simply equal to the length of the armature.

The equation (130) gives—

$$Z = N\,s\,L\,D\,n^2\frac{0{\cdot}83}{10^{10}} = \frac{490 \times 30 \times 60 \times 115 \times 90{,}000 \times 0{\cdot}83}{10^{10}}$$
$$= 756 \text{ kgrm.}$$

We will assume, for purpose of calculation, that five bands of binding wire are used in the 60 cm. length, each band being 20 mm. in breadth, wound from bronze wires 1·5 mm. in diameter (section of wire = 0·78 sq. mm.).

The section of all the wires will, therefore, be equal to

$$5 \cdot \frac{25}{1{\cdot}5} \cdot 1{\cdot}75 = 116 \text{ sq. mm.}$$

Breaking weight = 116 × 46 = 5,340 kgrm.

We have, therefore, *in this case a coefficient of safety smaller than that secured in other parts of the machine.* Moreover, we have taken no count of the forces acting on the cross-connections at the ends of the armature. For this reason it will be well to use a siliceous bronze or steel wire.

Example 2.—Suppose that for a machine of 25 kw. we have

$$N = 340;\ s = 9;\ L = 25;\ D = 30;\ n = 1{,}000.$$

The dynamo is furnished with a winding *en chignon*.

As a consequence we have

$$Z = \frac{340 \times 9 \times 25 \times 30 \times 1{,}000 \times 0{\cdot}83}{10^{10}} = 190 \text{ kgrm.}$$

Taking four bands, each of 20 mm. breadth, and formed from a layer of bronze wire of 1 mm. diameter (section 0·78 sq. mm.), the breaking weight will be

$$4 \frac{20}{1} 0{\cdot}78 \times 46 = 2{,}870 \text{ kgrm.}$$

We have, therefore, in this case a coefficient of safety of 15.

Example 3.—We will finally occupy ourselves with a case where the binding wires were really too weak. It is furnished by a dynamo of 240 h.p., making 350 revolutions per minute. The dimensions and other particulars of the machine are as follows:

$$D = 122 \text{ cm.}; \quad N = 228; \quad s = 100 \text{ sq. mm.}$$

Let us suppose L to be equal to 75 cm., taking into account the end connections. Consequently equation (130) gives us

$$Z = \frac{228 \times 100 \times 75 \times 122 \times 350^2 \times 0{\cdot}83}{10^{10}} = 2{,}140 \text{ kgrm.}$$

The armature was furnished with four bands, each consisting of 18 siliceous bronze wires of 1·5 mm. diameter. During the working of the machine a lateral sliding of the binding wires was produced in such a manner that they left the grooves provided in the armature and rested on the iron. Moreover, the diameter of the circular bands of wire was increased by 2 mm. during this process. We will now examine whether such an extension could not have been anticipated from calculation.

The section of all the binding wires was

$$4 \times 18 \times \frac{1{\cdot}5^2 \pi}{4} = 127 \text{ sq. mm.},$$

corresponding to a breaking weight of

$$\frac{2{,}140}{127} = 1{,}690 \text{ kgrm. per sq. cm.}$$

Let us take the modulus of elasticity E = 900,000;

unhappily, circumstantial information on the subject of such values is not generally given in text-books. We shall then have a lengthening

$$\Delta L = L \times \frac{Z}{E} = 122\ \pi \frac{1{,}690}{900{,}000} = 0{\cdot}72 \text{ cm.},$$

from which it may be seen that an increase will occur in the diameter of the windings amounting to $\frac{0{\cdot}72}{\pi} = 2{\cdot}3$ cm. nearly.

We see therefore that the sliding of the binding wires was necessarily produced. Further, this defect could easily have been avoided by making the number of bands equal to six, and in replacing the bronze wire by a steel pianoforte wire, which is well adapted for such a purpose.

We will here observe that in making use of steel wire we are obliged to use acid for soldering. As a consequence, the whole should finally be carefully cleaned with benzene. The acid must also be carefully prevented from reaching the insulation of the armature windings.

The three preceding examples, which we could multiply indefinitely, suffice to show that we should proceed with great caution in the choice of metal for binding wires, and that a calculation to confirm this choice is necessary. The larger the dynamo is, the greater become the necessary precautions, on account of the increased length of the wire.

In many cases we will be obliged to use an *auxiliary collector* (see Fig. 208*d*) conjointly with the windings on the two faces of the armature. Good results may also be obtained with the arrangement represented in Fig. 208*e*, which is, besides, much less costly and more easily constructed than the preceding.

In the new types designed by the author, and patented by the house of J. Farcot (Figs. 192 and 193), the cross-connections are attached to the discs of the armature by means of an arrangement specially provided. This arrangement, when applied to the ends of a commutator, entails the advantage that the commutator sections are relieved of the pull due to the centrifugal force acting on the windings.

We will finally give a few further rules to be observed in regard to the disposition of binding wires, though everything of this nature is generally left to the discretion of the winder.

Fig. 210 shows a very elegant arrangement for holding a number of binding wires together, due to the Oerlikon Company. The interior surface is formed of a layer of cloth, on which is placed a ribbon of mica. The sheet copper has a thickness of about 0·1 mm. to 0·15 mm., and is bent over on each side (see Fig. 210). In one of the apertures thus left is introduced one end of the wire, which is kept in position by means of a twist, whilst the other end of the same wire is provisionally placed in the other aperture. The windings being finished, they are soldered together at five or six places, and the free end of the wire is pulled through its aperture. The ends of the wire are finally bent in the manner shown in the figure, the whole being subsequently soldered.

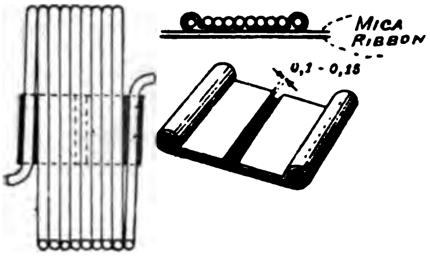


FIG. 210.

It is not wise to apply solder the whole of the way round the windings. In fact, in that case a tendency to get heated, due to the production of Foucault currents, will be displayed, which will ultimately lead to the whole arrangement becoming unsoldered. For the same reason, bands having a breadth greater than 20 mm. should not be employed, a couple of narrower bands, separated by 2 mm. or 3 mm., being advantageously substituted. These bands could further be wound continuously, unless there is any reason to cut the wire at the point of separation.

7. *Brush-Holders and Brushes.*

Small motors, as well as those designed for vehicular traction, are generally furnished with fixed brushes; on the other hand, in large motors and generators the brushes should be capable of displacement.

Further, it is important to arrange the brushes so that they can be displaced parallel to the axis of rotation, in order to prevent the armature from becoming ridged or conical. It is also advantageous, as was shown by Brown, to cut a groove

between the armature and that part of the commutator on which the brushes rub.

Different types of brush-holders differ only slightly one from another.

Generally, the brush-holders are mounted on the bearing in such a manner that they can be turned by the aid of a lever furnished with a clamping screw. It is only in very large machines that it is preferable, following the example of American makers, to employ a special support bolted to the base-plate, and carrying arms on which the brush-holders are so disposed as to admit of the requisite adjustments.

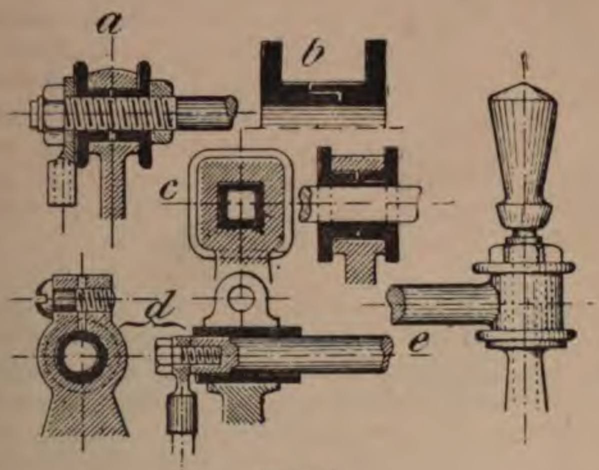


FIG. 211.

Mechanical displacement by means of screws and helical wheels presents the advantage that the brushes may be adjusted exactly to any required position, but this can be done directly with sufficient accuracy in any good machine below 50 h.p. in which the pole-pieces are not too close together, whilst the neutral zone is sufficiently large.

The usual method of insulating the trunks of brush-holders is shown in Fig. 211, and needs no further explanation.

When the pressure is greater than from 100 to 150 volts it is important that the surfaces should be well insulated; as a consequence, the discs should be from 8 mm. to 15 mm. larger than the cast-iron socket.

The point of separation of the insulating sockets presents some danger, since, even in the case where they touch each other, the possibility of sparking is not excluded.

This inconvenience can be obviated by the aid of the arrangements *b* and *c*. An equally simple arrangement is shown in Fig. 211*d*. It presents the advantage of permitting the trunk of the brush-holder to be drawn back, and for that reason is very useful when the distances between the trunk of the brush-holder and the commutator, and between these and the armature windings, are too small to permit of the brushes being lifted from the side. For the same reason it is not wise to make the nut at the right side (Fig. 211*a*) of a single piece with the trunk. Fig. 211*e* shows, finally, an arrangement frequently used by Mr. C. L. Brown.

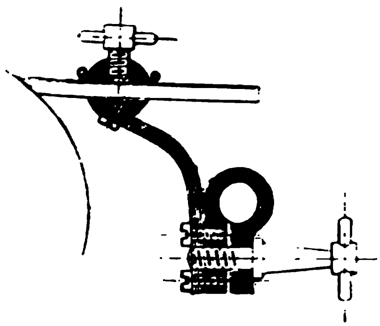


FIG. 212.

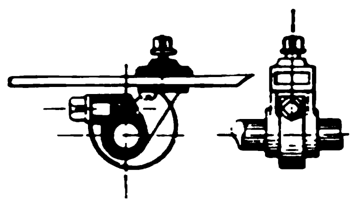


FIG. 213.

Some makers make use of brush-holders which allow us to raise the brushes simultaneously by the aid of insulated levers or gear wheels. Although brush-holders of this sort become more complicated and costly, they may be advantageously used when, for example, the dynamo is driven by a steam-engine, which might reverse its sense of rotation at the moment of starting.

When carbon brushes are employed, this precaution is unnecessary.

Carbon Holders present so many different forms, that we should far exceed the limits of the space at our disposal if we were to enumerate all the arrangements which are at the present time employed. Fig. 212 is, without doubt, the

form most generally used, and most simple in construction. To ensure it giving satisfaction the following points must be observed:

1. The spring should be formed of a good conducting and elastic metal, most often of cold-hammered copper or sheet brass, of 0·2 mm. to 0·5 mm. thickness.

2. The angle which this spring makes should not be too small, otherwise the brushes may be displaced in the act of clamping.

Figs. 213 and 214 show two arrangements designed by Mr. Brown, of which the first is altogether the superior; numberless variations of this form are to be found. We could, perhaps, urge against this design that the spring approaches rather too close to the commutator. The brush-holder due to Alioth, and represented by Fig. 234, is equally well known.

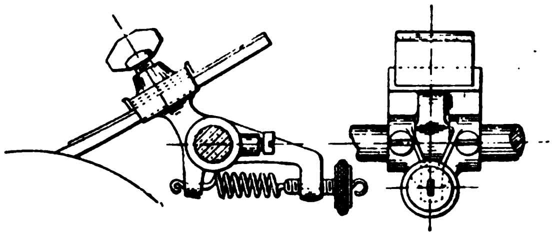


FIG. 214.

During some time the use of metallic brushes has been diminishing, being confined at the present time chiefly to machines producing very strong currents. Carbon brushes have been used for at least 10 or 11 years. Originally proposed by Prof. Forbes, they were first used in the United States, especially for tramway motors, which must be able to turn in either direction. Later on they fell into discredit; this was simply due to a lack of knowledge of the following conditions, which must be fulfilled in order that these brushes may work well:

1. The commutator sections should be made from copper as hard and homogeneous as possible, and the insulating substance between them (most often mica) should not be too hard, and should wear away uniformly with them.

2. The carbons should conduct as well as possible, and should be neither too dry nor of a material which is too greasy.

3. The peripheral velocity at the commutator should not exceed 10 m. or 11 m., and, when possible, should be kept below 8 m. or 9 m. per second.

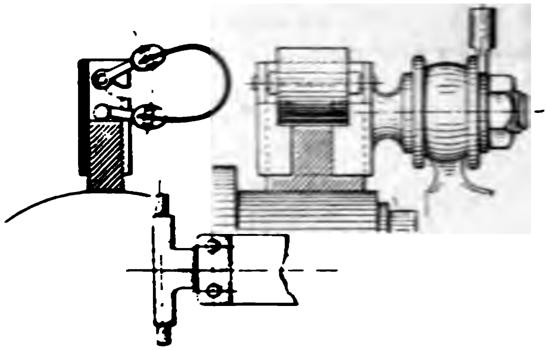


FIG. 215.

4. The brush-holders should be as light as possible, so as not to vibrate on passing over the unavoidable rugosities of the commutator. For this reason, carbons with inclined contact surfaces are recommended.

Nothing is more prejudicial to the good working of a dynamo furnished with carbon brushes than any looseness of the commutator sections: under these conditions sparks will occur in a dynamo however well it may be constructed in other respects. The only remedy which can be applied is the use of metallic brushes, unless, indeed, it is decided to screw the commutator up tighter and turn its surface true so as to remove the disturbing cause.

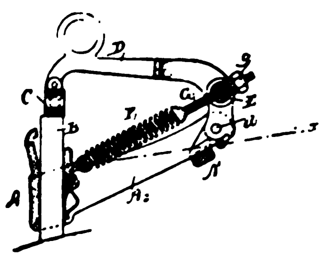


FIG. 216*a*.

Figs. 215 to 217 represent three types of American brush-holders.

Fig. 215, that due to Lundell.

Fig. 216, that due to the Westinghouse Company (for tramway generators).

Fig. 217, that due to Wood.

Thury's carbon holder (constructed by La Compagnie de l'Industrie Electrique de Genève), shown in Fig. 218, is

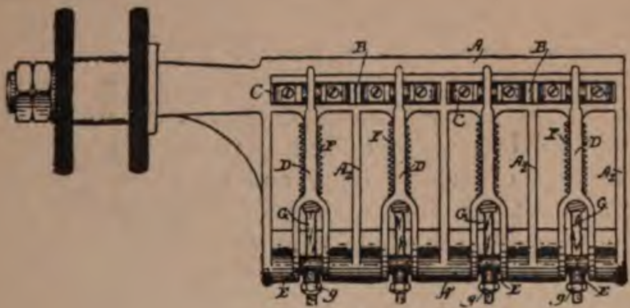


FIG. 216*b*.

constructed on a new and rational principle. In place of modifying the dimensions of each brush to correspond to the

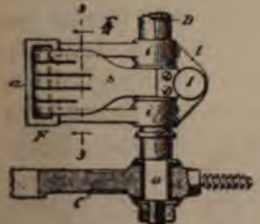


FIG. 217*a*.

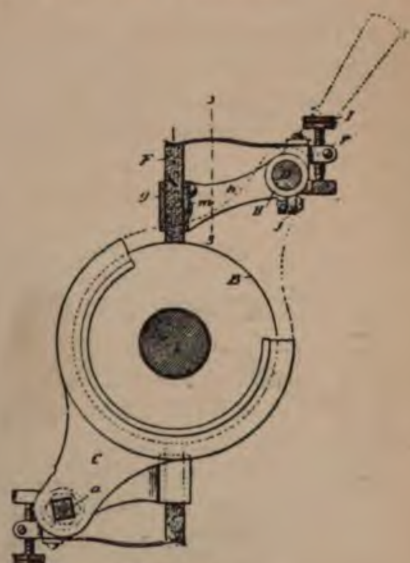


FIG. 217*b*.

current which is to be carried, M. Thury has adopted the plan of mounting an appropriate number of brushes all of the same size on the trunk of the brush-holder. By this

means, not only is the cost reduced 1s. 10d. to 2s. 1d. per brush-holder, but a better contact is realised. The manner in which the current is transmitted is not absolutely irreproachable: in fact, this is effected partly by means of the galvanised iron cheeks, punched out in a machine from wrought sheet iron, and in part by a thin piece of sheet copper. The use of small pieces of carbon, maintained in position by means of a metallic framework which can be displaced in a brush-holder fixed by means of a spring, offers the advantage of great solidity and an absence of noise in working. Moreover, in the three brush-holders of which we are about to speak, the whole length of the commutator may be more or less utilised. On the other hand, the length of the pieces of carbon is relatively smaller.

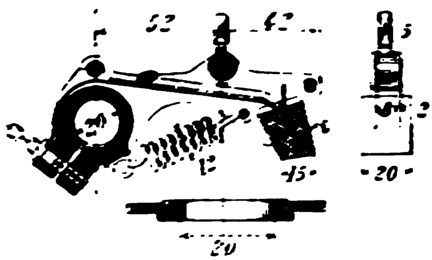


Fig. 218.

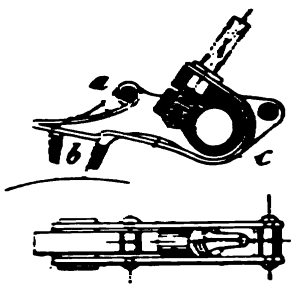


Fig. 219.

In the brush-holder due to the Oerlikon Works (Fig. 219), (constructed after the model of that of M. Thury), the electrical contact of the carbon plates is rather better; the cheeks are also in copper. The flat spring, *a c*, serves two useful purposes: the part *a b* is designed to press the carbon against the holder, whilst the part *b c* ensures the elasticity of the whole arrangement. In this case, for greater security, a piece of sheet copper is placed under the flat spring.

The brush-holder for carbon brushes (Fig. 220) designed by the author, and used in the dynamos constructed in the works of Farcot, at Saint-Ouen, depends for its success on an application of the same principle. The two cheeks are punched from sheet brass, and are hammered to obtain greater stiffness. The form of the carbons here used is slightly different from those previously described; this form allows

the carbons to be used under better conditions; moreover, it is impossible that the brushes should be displaced when the screw is tightened.

The possibility of the screw becoming loose on its own account has also been provided against.

Fig. 221 represents a simple arrangement for a carbon brush-holder to be used on a small dynamo; here the metallic spring is replaced by a band of caoutchouc.

We will finally mention the fixing arrangement for carbons (Fig. 221*b*) due to Alioth, as well as that due to Siemens and Halske (Fig. 222), which is often employed.

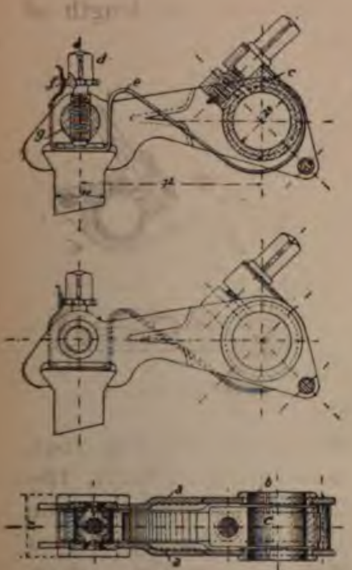


FIG. 220.

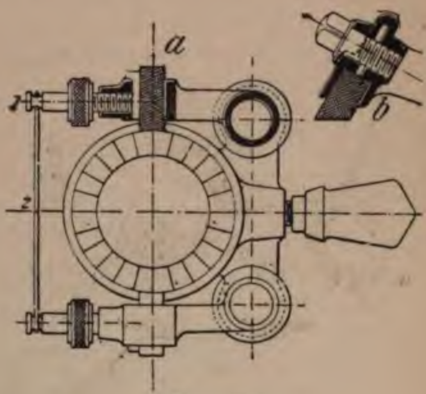


FIG. 221.

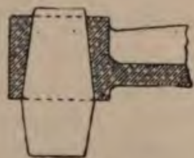


FIG. 222.

As to the materials from which brushes should be made, reference must be made to p. 298. The *pressure of the brushes* should be from 100 grm. to 150 grm. per square centimetre of the contact surface; but in tramway motors this pressure should be increased to 250 grm. or even 300 grm.

It is necessary that not less than two brushes should be mounted on one trunk, so that one may be removed without interrupting the current.

B. Field Magnets.

1. *Field-Magnet Cores.*

A little while ago the attention of inventors seemed mostly occupied with the design of new arc-lamp mechanisms; at present the most popular task (especially in the United States) seems to be the design of new types of field magnets. Few days pass, indeed, without some new form appearing on the market. In many cases the new forms appear well adapted for the purposes for which they were designed; but it cannot be denied that the greater number of them owe their existence to the need felt by inventors to produce something novel. For this reason we have no intention of describing the various arrangements of field magnets. Plate II., at the end of this book, contains a rough schematic sketch exhibiting 42 typical forms, and needs no further description.

Dynamos are often constructed from cast steel. For portable motors (for tramways, etc.), as well as for dynamos in which the weight plays an important part, the use of that metal is rational enough: but when it comes to ordinary dynamos for electric lighting we should take the following considerations into account.

As is shown by Plate I., the same number of ampere-turns which is necessary for 7,400 lines of force per square centimetre in cast iron, will suffice to produce 15,000—that is to say, nearly double the number of lines of force if cast steel be employed. In other words, to produce a given number of lines of force, ϕ, we must give to a cast-iron magnet a sectional area twice as great as that required when cast steel is used. But as the price of cast steel is from 2½d. to 3d. per pound, whilst that of cast iron is from 1¼d. to 1½d., the costs of the metal employed in the two cases will be nearly equal.

On the other hand, all workshops do not possess a foundry for steel, whilst few will be found wanting in one for cast iron. Consequently, if steel field magnets are required, the work will be considerably retarded (often by about three or four weeks). Further, to the cost of the cast iron the cost of transport and retouching must be added. It should be finally remembered that, when cast-steel field magnets are used, the body of the machine cannot be cast in iron together with

the journals. In short, in making a comparison of the advantages and disadvantages, it will generally be found best with large machines to make the body of the machine of cast iron and the cores of the field magnets of cast steel of a circular section; the weight of the copper finally used will thus be found much reduced.

This does not apply to cases where cast steel costs less than 2½d. per pound, when the choice should be in favour of cast steel.

2. *Field-Magnet Bobbins.*

Space for Winding.—It is necessary to avoid too great limitation of the space reserved for the field-magnet windings.

Turning to the formulæ (64, p. 88) we find that the space necessary for the field-magnet windings is determined by the product $s \times N$. But we have

$$s = \frac{(C_m N_m) N'_m \, L}{E \, 50},$$

and

$$N_m = \frac{C_m N_m}{C_m.}$$

Multiplying these two equations together, and taking account of the space which must be allowed for the necessary insulation, we see that the total space, F, which must be reserved for the windings, is given by the equation

$$F = c \, s \, N_m = c \, \frac{(C_m \, N_m)^2 \, L}{50 \, w}, \text{ in millimetres.}$$

In this formula we designate by

w, the loss in watts per bobbin;

$(C_m \, N_m)$, the number of ampere-turns per bobbin;

L, the mean length of a turn, in metres;

c, a coefficient (see following tables).

We may distinguish between two species of windings.

In the first, each turn of a particular layer is wound so as to lie between two turns of the lower layer (Fig. 223*a*). In the second the wires are directly superposed in winding (Fig. 223*b*). As the first method is particularly applic-

able to conical windings, we will call this ***conical winding***, whilst the latter method will be called ***rectangular winding***.

The coefficient c decreases with the diameter of the wire, and its values are given in the following table.

TABLE OF VALUES OF c.

Diameter of wire in mm. =	0·5	1	2	3	4	5 and more
Rectangular winding c =	5	2·9	2·15	1·86	1·68	1·57
Conical winding c =	3·75	2·2	1·4	1·9	1·26	1·18

Suppose that

N = total number of turns in a bobbin.

N_1 = ,, ,, ,, ,, in the lowest layer.

The number of layers will be in the case of a conical winding

$$(N_1 + \tfrac{1}{2}) - \sqrt{(N_1 + \tfrac{1}{2})^2 - 2\,N_m}.$$

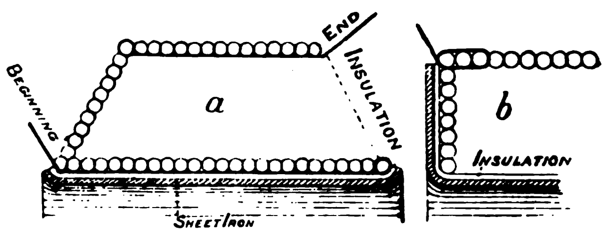


FIG. 223.

When a core with a circular section is used, instead of one with a rectangular section, we can economise by about 10 to 12 per cent. of the copper. If we replace a core of cast iron with a rectangular section by one in cast steel with a circular section, the weight of copper used is decreased by from 30 to 35 per cent.

Construction of the Bobbin.

The shell of the bobbin is generally made of compressed card, isolite, amianthus, or Vulcabeston. Ebonite is not well adapted for this use, since it buckles badly when heated.

In many dynamos we find the shell composed of iron or sheet zinc and insulated with cloth or paper, the extreme cheeks being made of wood. In the case where a conical winding is employed, a shell in iron or sheet zinc with a paper insulation may rationally be used; the edges of the metal should be bent round so as to secure an attachment between the wires and the bobbin, as shown in Fig. 223*a*.

In order to fix the bobbins to the field magnets, use is made of bolts or angle pieces; these are used throughout when the shell is made from an insulating material. In cases where iron is used in making the shell, lugs may be riveted on to the latter, and these may be bolted to the core. In case of conical windings the extreme wires of a layer must be held in their places by several turns of ribbon.

Conductors for the Main Current.

It is not wise to prolong the wires directly to the terminals; for these connections, cables or ribbons of copper

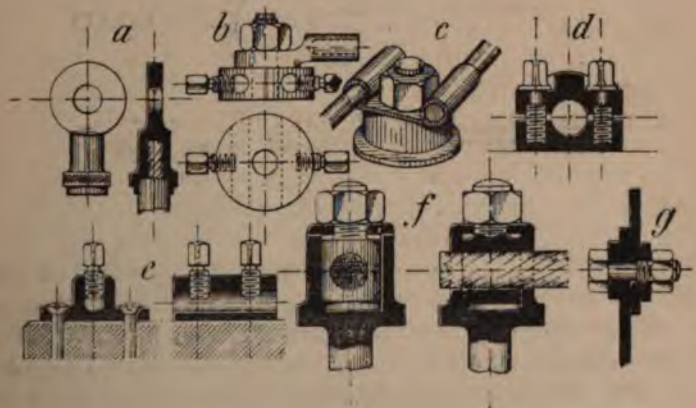


FIG. 224.

are always employed. The latter are very useful for connecting different coils between themselves, which may be done by screwing the ends of two of the ribbons together. To prevent a rupture in the connection, we may solder the copper ribbon to several turns of the winding (Fig. 224*b*). Another

very good arrangement is to wind the whole of the last layer over the insulated metal ribbon, which is to be used to convey the current to the terminals. If a mica insulation is employed, the exterior aspect of the coil will not be affected.

The firm of Gebr. Adt, at Ensheim, Alsace, as well as other makers, manufacture shells for the field-magnet windings from compressed card (isolite) in which the end of the wire is placed in a groove made for that purpose.

Although the arrangement of the connections of the field magnets appears to be of little importance, yet the method to be used should be carefully considered. Indeed, when this part of the work has not been well executed, the whole dynamo presents a miserable aspect, and gives one the idea of hasty and discreditable work.

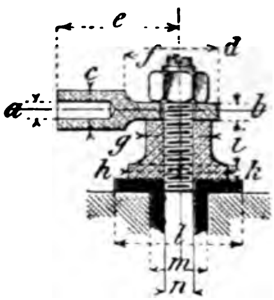


FIG. 225.

The same thing may be said of the construction of the field-magnet coils in general. Particular attention should be paid to the places where one layer ends and the next begins. In spite of all the trouble with which this work may be executed, crossings are always formed here which present an appearance anything but elegant. For this reason the defective side should be placed, when the bobbin is finally mounted in position, so as to escape observation.

Further, windings composed of thin wires often present the inconvenience that the external surface of the windings is irregular. We could avoid this inequality by placing, below the last layer or two, a sheet of cardboard of sufficient resistance on which the final windings may be evenly executed. This is only possible, however, in case of rectangular windings.

Another procedure, mostly employed in the United States, is to finish the winding of the field magnets with a layer formed of a number of turns of thick cord (*septin*), which presents an agreeable appearance, besides affording an excellent protection to the enclosed wire.

C. Terminals.

TABLE OF DIMENSIONS OF TERMINALS.

(See Fig. 225 for meaning of letters.)

Amperes	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*k*	*l*	*m*	*n* mm.*	*n* inches
5	2	2	6	15	22	11	13	19	9	3	25	12	6	$\frac{1}{4}$
10	3	2	7	15	24	12	13	19	9	3	25	12	6	$\frac{1}{4}$
15	4	3	8	15	26	13	13	19	9	3	25	12	6	$\frac{1}{4}$
25	5	3	10	19	30	14	16	24	10	4	32	15	8	$\frac{5}{16}$
35	6	4	11	19	34	15	16	24	10	4	32	15	8	$\frac{5}{16}$
50	7	5	13	19	38	16	16	24	10	4	32	15	8	$\frac{5}{16}$
70	8	5	14	24	42	18	20	30	15	5	40	18	11	$\frac{3}{8}$
100	10	6	16	24	45	20	20	30	5	5	40	18	11	$\frac{3}{8}$
150	12	7	17	30	50	20	25	36	17	6	48	21	12	$\frac{1}{2}$
220	14	8	20	30	55	24	25	36	17	6	48	21	12	$\frac{1}{2}$
300	17	9	26	38	65	28	32	48	20	7	60	26	16	$\frac{5}{8}$
400	20	10	30	38	70	30	32	48	20	7	60	26	16	$\frac{5}{8}$
550	25	12	37	45	80	32	40	60	22	8	75	31	20	$\frac{3}{4}$
750	30	15	45	55	95	40	50	75	26	10	90	37	25	1
1,000	35	17	50	66	100	45	60	85	30	10	100	44	30	$1\frac{1}{4}$

* French screw gauge (Societé d'Encouragement).

D. Screws for Tightening Belts.

When dynamos are not coupled directly to the engine which drives them, they should be always supplied with screws for tightening the belts. The price paid for these is insignificant in comparison with the advantages gained by their use. In the case of dynamos of average output, we may content ourselves with two rails provided with a couple of adjusting screws. Large machines require a third rail in the midst of the base without an adjusting screw.

Fig. 226 shows a certain number of arrangements.

Fig. 226*a* is the most used arrangement. In Fig. 226*b*, the advantage of being able to considerably shorten the screws is manifest; however, for large machines the

preference must be given to the arrangement shown in Fig. *a*, or, better, the carriage may be furnished with a screw which is in tension when producing a displacement in the required direction. When a square-threaded screw is

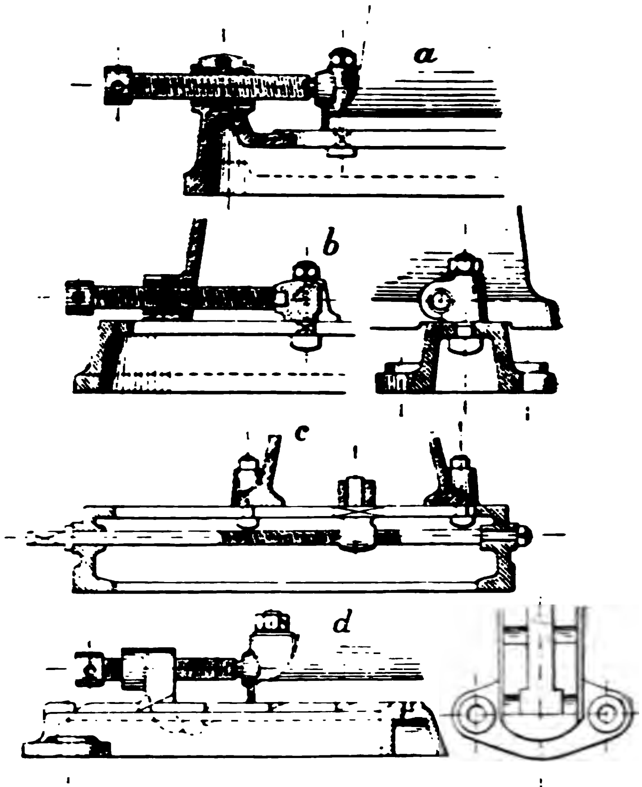


FIG. 226.

used, the expense of cutting a special nut to fit it can be avoided by casting one on the screw in some special alloy.

CHAPTER IX.

Description of some Types of Dynamos.

After having in the last chapter passed in review the different parts of a continuous-current dynamo, we will in the present one give a certain number of designs and views of complete machines.

We shall seek, on the one hand, to present a tolerably complete account of the rational combinations of the various elements of such machines, and, on the other hand, to give some information respecting recent improvements in dynamo design throughout the world.

As, in general, the study of machine design should precede that of the applications of electricity, we shall dispense with giving perspective views whenever such are not required to render the diagrams intelligible. Moreover, we have made a point of including no dynamo which cannot be considered as typical, whatever its origin may have been.

Oerlikon Works.—Figs. 227 *a* and *b* show two diagrams of a *bipolar dynamo designed for electric lighting purposes by the Oerlikon Company*. It could be considered as typical of a great number of machines in which the special feature is a double magnetic circuit, with the bobbins placed directly in the neighbourhood of the poles. Amongst other advantages of this special type, we may mention the simple form joined to reduced weight, together with a very small external stray field (any leakage which occurs being chiefly in the interior of the machine), all of which render this type very suitable for small motors of less than 20 h.p. It is, indeed, the type of machine which we most often meet with. In order to improve its appearance, the armature is furnished with a cloth covering, which is maintained in position by means of two bands.

In the case of Fig. 228 (*a* and *b*), which represents a more ancient type of machine constructed by the same firm, which

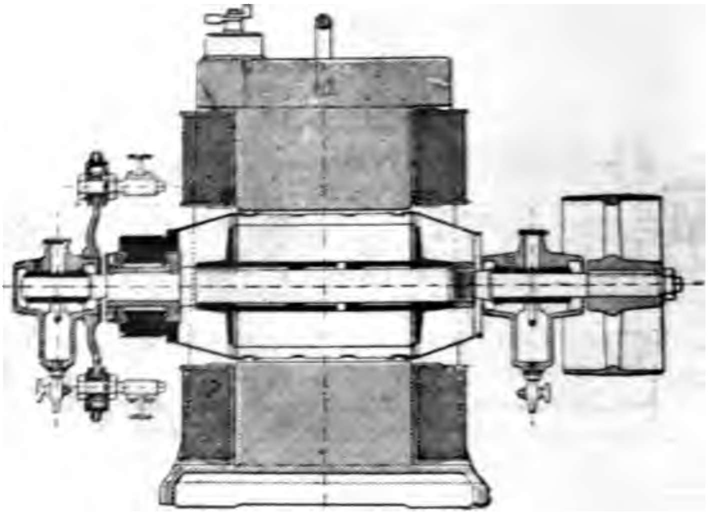


FIG. 227*a*.

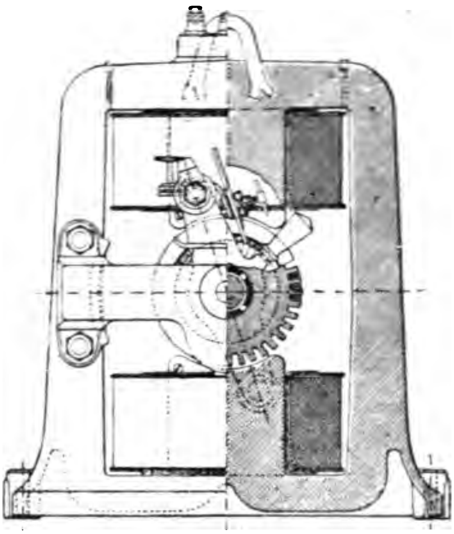


FIG. 227*b*.

is still, however, used for the transport of energy at a high voltage, we once more find the double magnetic circuit, but

each element now possesses a special bobbin. Concerning the lubrication, we may add that in all recent machines

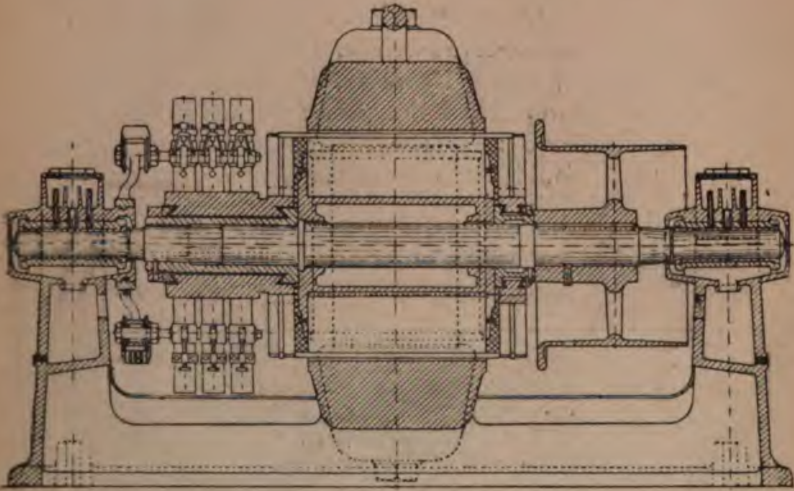


FIG. 228*a*

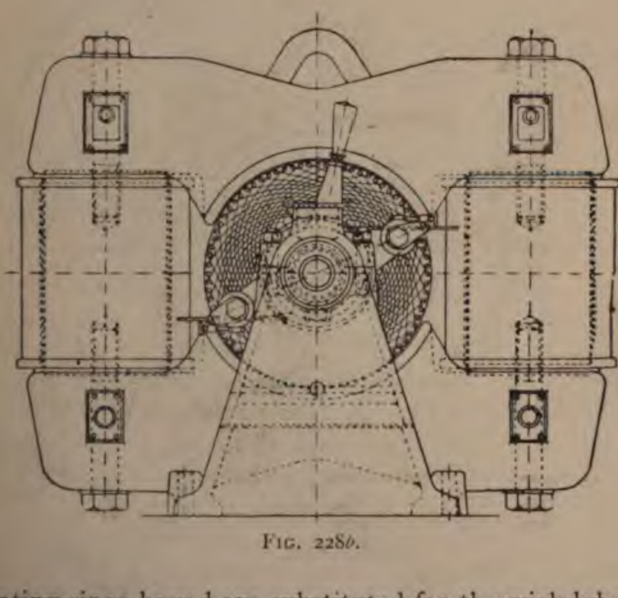


FIG. 228*b*.

lubricating rings have been substituted for the wick-lubricators found in the earlier types.

This type of machine, known as the "Manchester" type (first built by Messrs. Mather and Platt), presents great advantages in regard to its form and in the method of its construction, in spite of certain faults—such, for example, as its excessive weight, the large amount of its magnetic leakage, etc. However, if it were necessary to construct a dynamo in which the weight should be reduced to a minimum, one after the Manchester type might be designed that would be no heavier than that previously mentioned. But in order to obtain a favourable external appearance, some concessions are usually made at the expense of the weight.

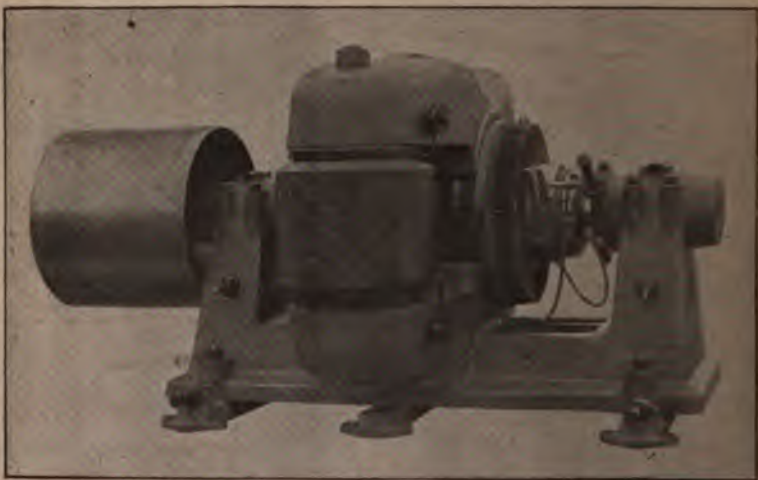


FIG. 229.

This type of machine has been perfected, as far as appearances are concerned, by the firm of Brown, Boveri, and Co. Fig. 229 is taken from a photograph of a machine made by this firm. Details of brush-holders and screws for tightening the belts have already been given in Figs. 211, 213, and 226*d*. A ring armature is employed.

Fig. 230 (*a* and *b*) refers to a four-pole dynamo made at the Oerlikon Works; the armature has been shown in Fig. 186 on a larger scale. In order that the armature may be easily removed, the upper half of the field magnets

is removable, an arrangement generally observed in large dynamos. The cores and the circular yoke of the field

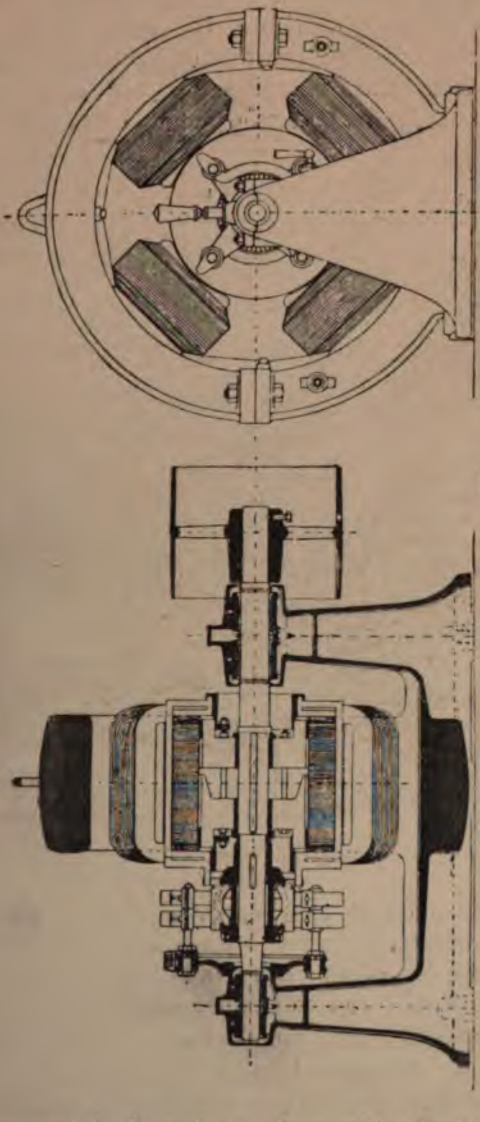


FIG. 230 *a* and *b*.

magnets are cast in iron, in a piece with the journals. The pole-pieces have been suppressed in order to simplify the work of adjusting.

Probably the first vertical dynamo ever made was constructed in the Oerlikon workshops; the use of large machines of this class in numerous installations has fully confirmed the advantages claimed for this form of construction. The six-pole dynamo of 120 h.p. (represented in Figs. 231 and 232) is used to excite the Thury generators employed in the transport of energy at Chevres, near Geneva. The weight

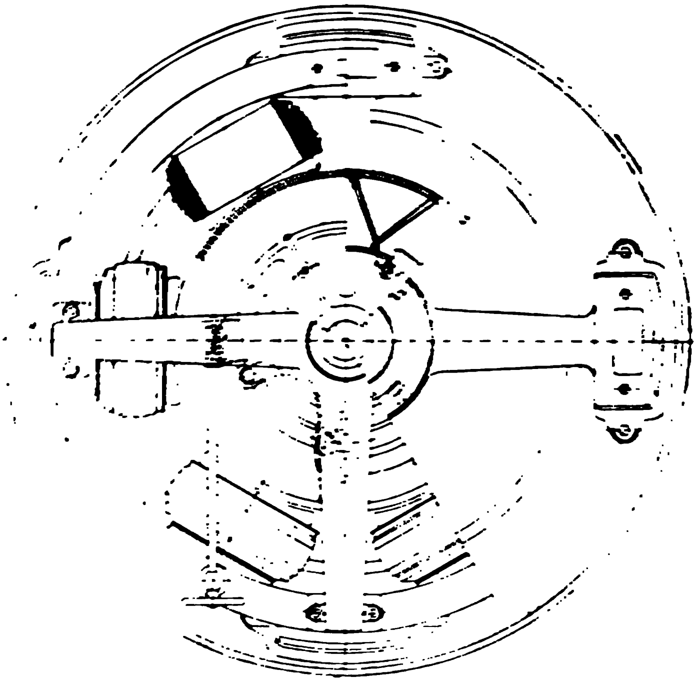


Fig. 231a.

of the armature is, as has been said, supported by the turbine. The bush of the inferior bearing is in two pieces, of the same diameter as the collar of the shaft, so that the latter may be withdrawn from above. Lubrication is effected by means of a sight-feed lubricator (shown on the left of Figs. 231 and 232). The upper bearing is lubricated directly, whilst a longitudinal hole in the shaft carries oil to the lower bearing. Oil-catchers are provided on both bearings.

The winding is effected according to the principles detailed

on p. 31. As it was necessary, for special reasons, that the commutator should be situated at the upper end of the armature, the latter is protected with a covering of cloth.

Alioth and Co. (Basle). — All the Alioth dynamos are multipolar, even those of 2 kw. They are characterised

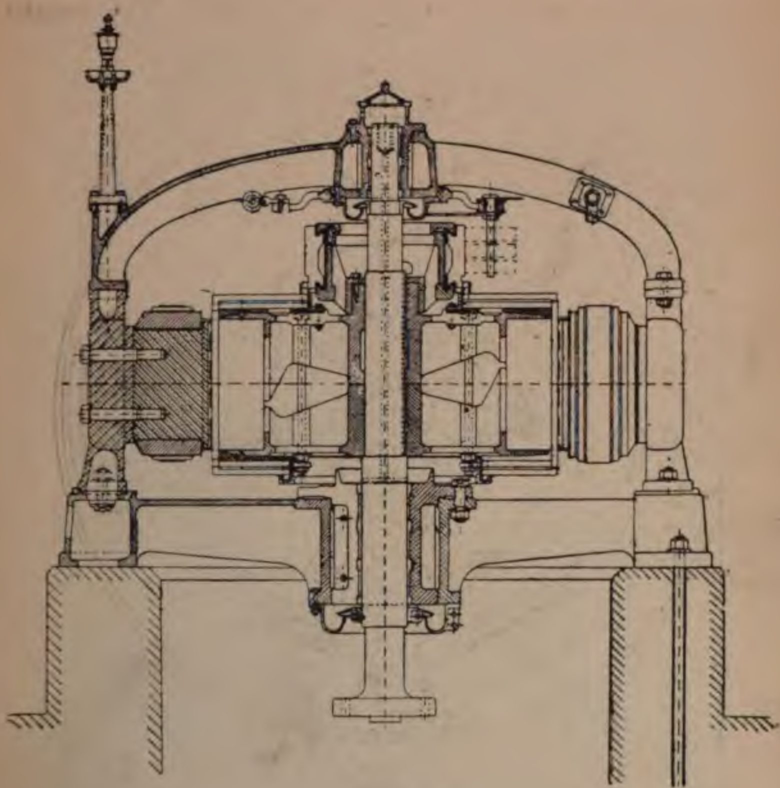


FIG. 231*b*.

by the round form of the field magnets and their favourable appearance. Figs. 233 and 234 show various particulars of a small dynamo of 15 kw. The poles of the field magnets are made of cast steel, and are bolted on to the circular yoke of cast iron.

The pole-pieces present this special point, that their edges are inclined; this arrangement is often seen in German machines. It permits us to decrease the angle of lead

of the brushes without increasing the magnetic leakage unnecessarily. The arrangement to effect an interior ventilation may be specially noted, as well as the cap-like form given to the support of the brush-holders, which is furnished with a toothed crown (Fig. 234), which serves at the same

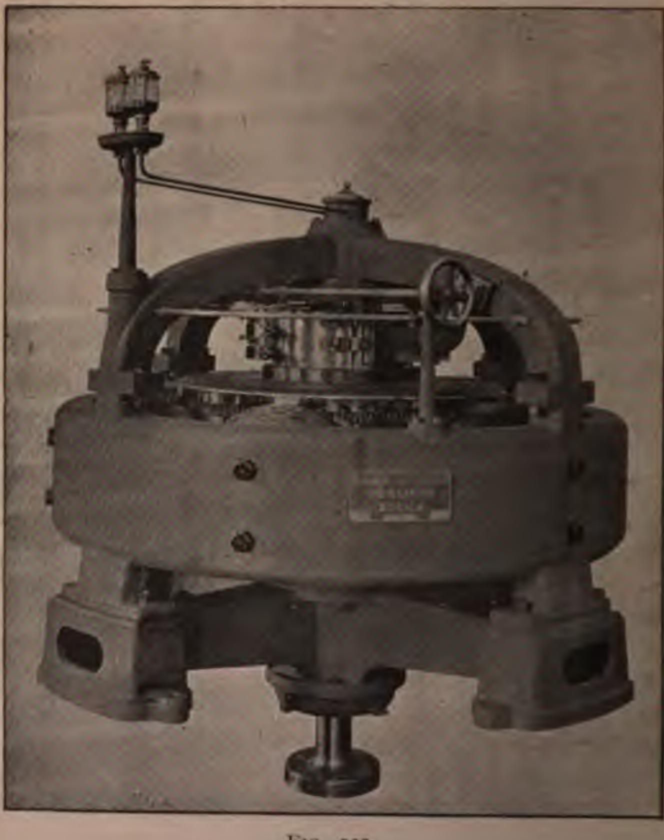


FIG. 232.

time to protect the armature. In small dynamos of this type the bearings are in a single piece; larger machines have these, as well as the circular yoke, in two pieces. The generator for the tramway station at Basle is constructed similarly (Fig. 235). That dynamo was exhibited at the Swiss Exposition at Geneva in 1896.

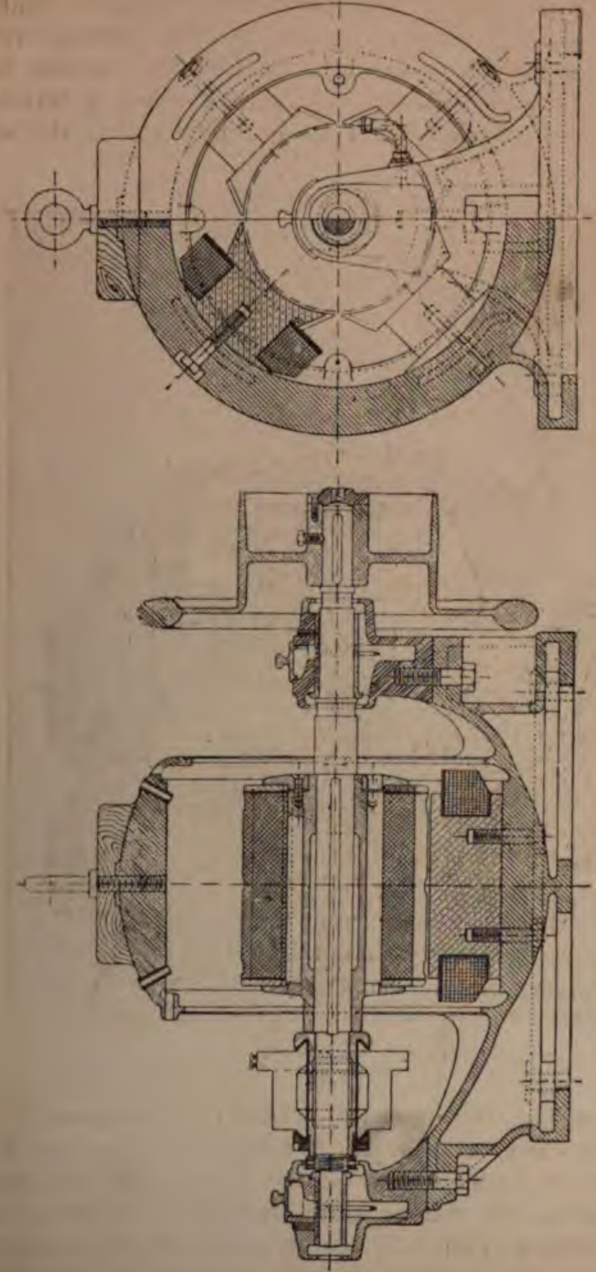


FIG. 233.—15 kw. Dynamo by Alioth and Co.

The following are some data with respect to this machine:

Output = 300 h.p.
Speed = 85.
Number of poles = 12.
Diameter of armature, D = 200 cm.
Length ,, l = 45 cm.
Number of commutator sections = 365.
Length ,, ,, = 13 cm.
Diameter ,, ,, = 130 cm.

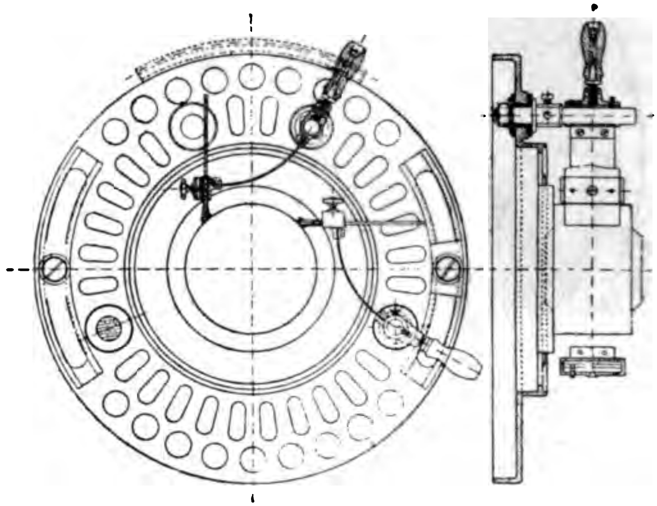


FIG. 234.

In this dynamo the current is collected by means of a special arrangement which takes the place of the loose cables which usually make connection with the brush-holders.

Compagnie de l'Industrie Electrique (*Société Thury*), (Geneva). This company has for several years constructed a type of dynamo (Figs. 236 and 237) which is characterised by field magnets of a special form. A specialty is made of installations for the transmission of energy at very high pressures. Thus the installation at Biberist has worked for six years at a pressure of 3,500 volts without stopping, except on Sundays.

It may be observed that these dynamos have been designed to work at a pressure of 5,000 volts, an unusually high value

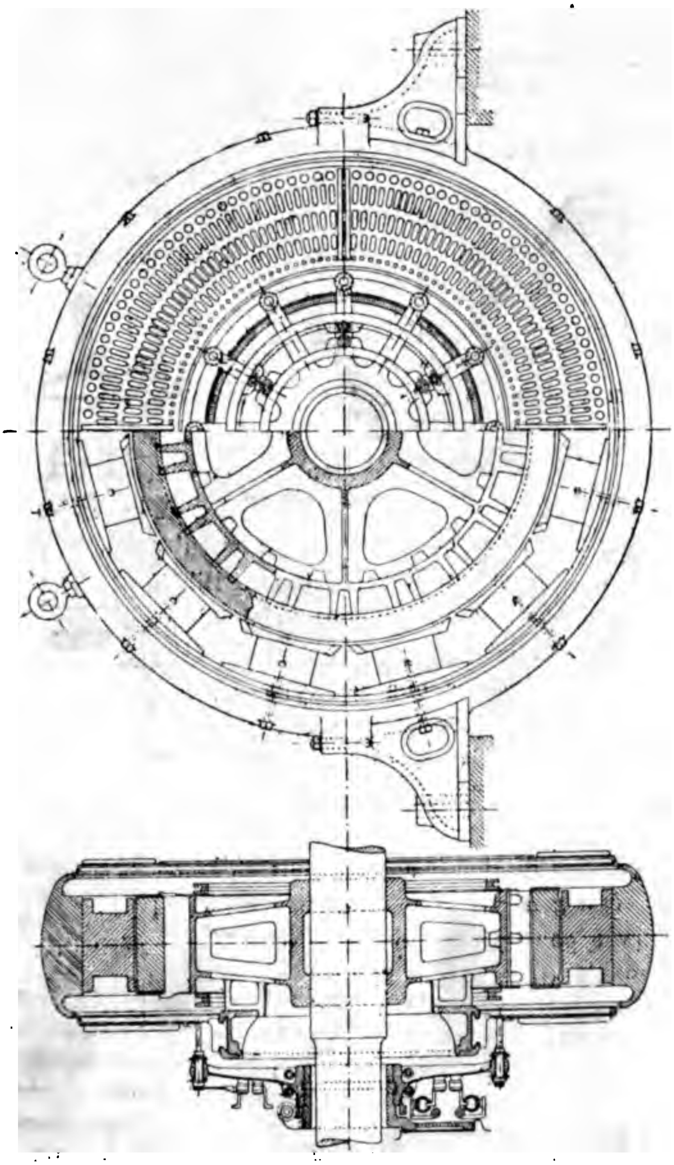


FIG. 235.—300 h.p. Tramway Generator, by Alioth and Co.

for Europe, though one often attained in the United States by arc-lighting dynamos.

The dynamos designed for the transmission of energy are, as a general rule, wound in series. However, M. Thury has

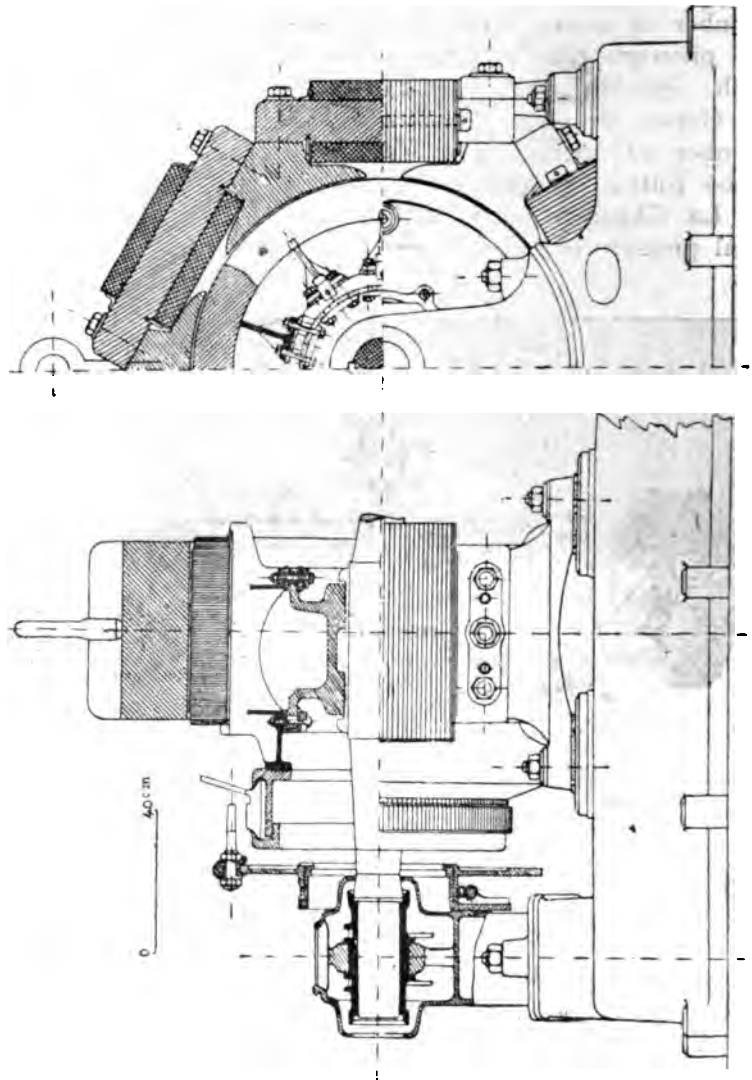


FIG. 236.—Dynamo of the Company l'Industrie Electrique, Geneva.

constructed shunt-wound machines working at 1,600 volts (!)—for transmission of energy at Stanserhorn.

The most characteristic point in the Thury system

consists in employing series-wound motors coupled in series, with a constant current strength, an invariable speed being obtained by the use of speed regulators, which vary the number of active turns in the field-magnet windings (see the photograph of a series motor, Fig. 237). In the first such installation for the transmission of energy, that at Gènes, three generating stations were provided; the number of motors was 22, and the complete pressure 8,500 volts. The pressure is still higher in the installation at La Chaux-de-Fonds and at Locle (eight units with a total pressure of 14,400 volts).

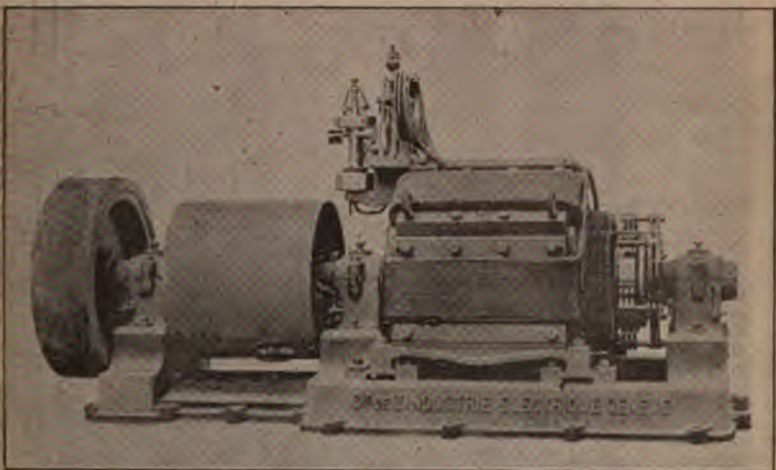


FIG. 237.

It goes without saying that in cases where high pressures are employed, the armature as well as the field magnets must be carefully insulated from the base-plate. Another precaution consists in mounting the dynamo on porcelain insulators, shaped like inverted bells, instead of on wooden beams.

For pressures up to 1,800 volts M. Thury employs drum windings; for higher pressures, ring windings are used. The field magnets, made of laminated wrought iron, merit special attention. Practice has led to the establishment of a certain small number of standard sections for the armatures; the dimensions for any particular machine are obtained by com-

bining one of these sections with an appropriate length of armature.

The following table contains some numerical information relating to Thury dynamos.

Horse-Power.	25 to 30	50 to 100	100 to 200	300 to 400	500 to 600	800	1,000	1,500
Speed	—	450	375	315	275	240	180	150
Number of poles...	4	6	6	6	8	8	10	12
Bore of field magnets	—	580	750	1,250	1,500	1,750	2,200	2,500

The following data apply to a vertical generator for the railway at Mont Selève, and correspond to the last column but one in the foregoing table.

Pressure = 600 volts.

Current strength = 275 amperes.

Speed = 45.

Armature = 451 coils, each consisting of four parallel wires. Diameter of bare wire = 3·3 mm.

Commutator:
- Diameter = 1,800 mm.
- Number of sections = 451.
- Number of lines of brushes = 12, each comprising three brushes.

Field magnets:
- β = 0·8.
- Diameter of wire = 7·5 mm.
- Current strength = 100 amp. } separate
- Pressure = 100 volts } excitation.

For very small motors M. Thury has employed a type often used in modern alternators, with a commutator of which the construction is indicated in Fig. 238 (English patent No. 29,226, Dec. 19, 1896). It may be remarked that the author had independently arrived at a similar design to that of M. Thury. The first drawing is dated June, 1895 (see also Plate II., Fig. 40, of the third German edition of the present work, published on Oct. 30, 1896). This is derived naturally from the ordinary type by suppressing all the positive *or* all the negative poles. As a consequence, in order that the magnetic circuit may be closed within the machine, *thus* avoiding unnecessary leakage, the shaft must be enlarged

so as to gather together the total magnetic flux. The winding of the armature is identical with that of ordinary machines.

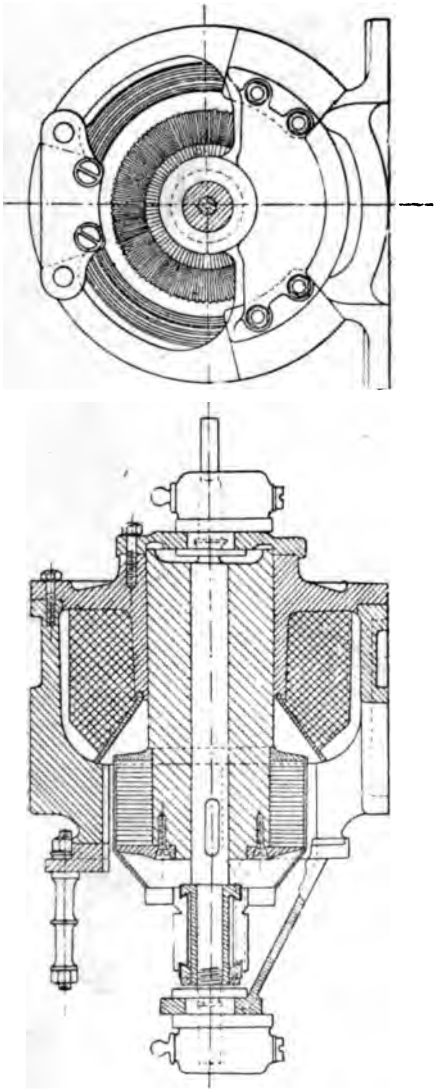


FIG. 238.

It may easily be seen that the pressure will be, for the same number of lines of force, equal to half that of an ordinary dynamo of similar dimensions and speed.

The following are some data with respect to this machine:

Output = 300 h.p.
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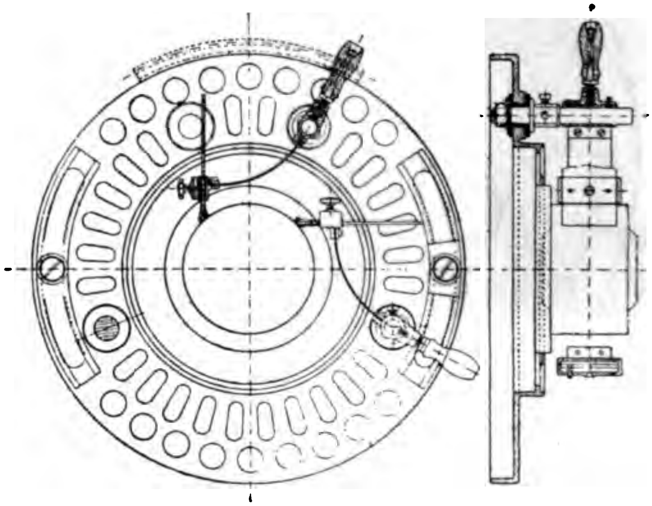

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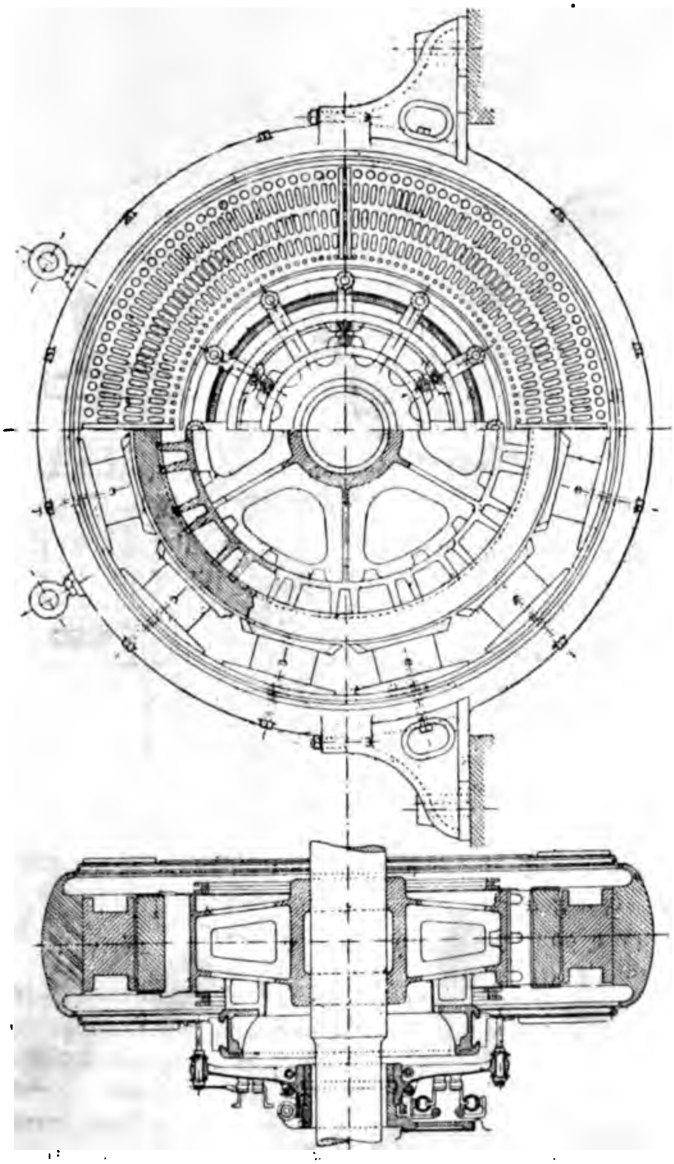

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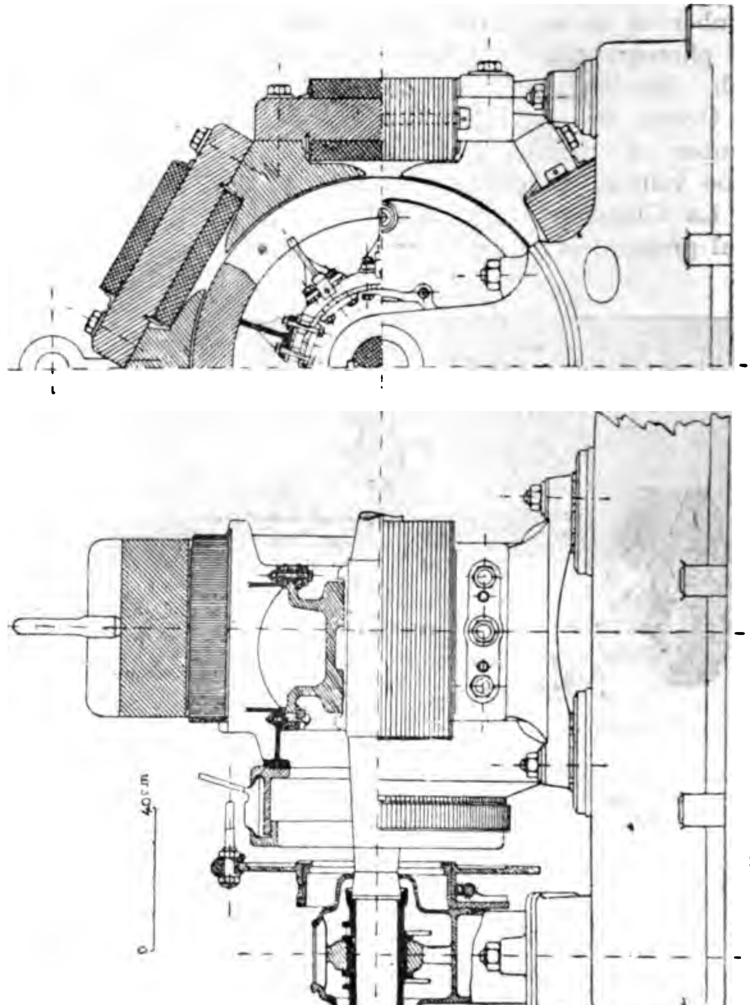

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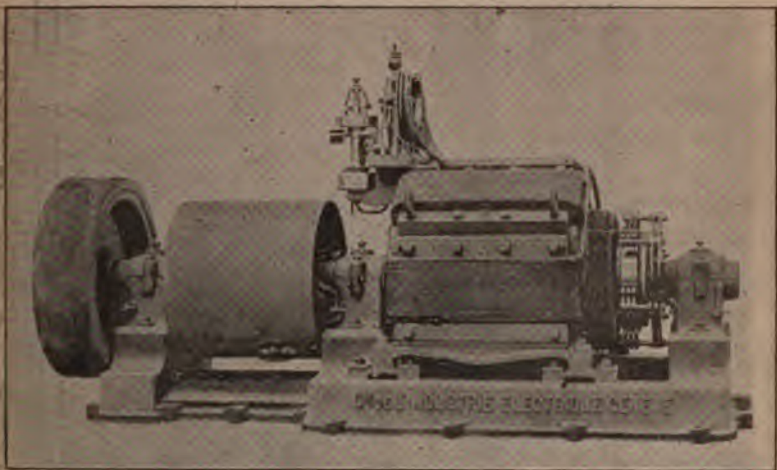

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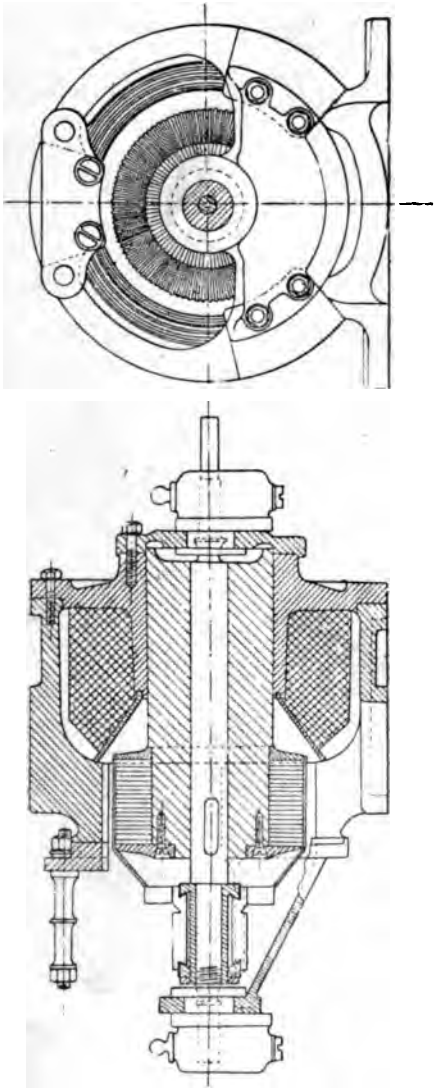


FIG. 238.

It may easily be seen that the pressure will be, for the same number of lines of force, equal to half that of an ordinary dynamo of similar dimensions and speed.

This great inconvenience is nevertheless compensated for by the possibility of employing a higher saturation and poles embracing a greater arc. In fact, whilst in an ordinary dynamo the polar arc is equal to about $\frac{D\pi}{3p}$, it can be made equal to $\frac{D\pi}{2p}$ in the form we are considering, unless the leakage is unusually great.

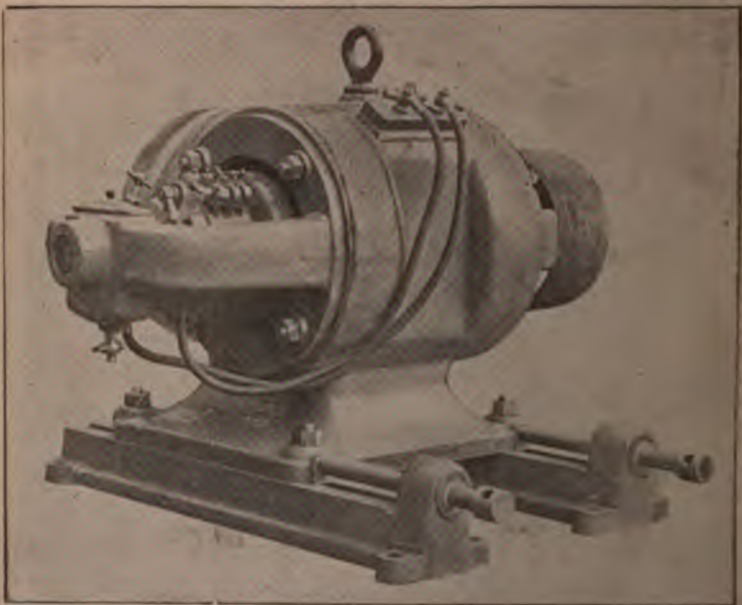


FIG. 239.—5 kw. Bipolar Dynamo, designed by the Author.

J. Farcot (Saint-Ouen).—Continuous and alternating current dynamos have been constructed in these workshops during two years from plans furnished by the author. A certain number of details of these machines have already been given; among others, the holder for carbon brushes which is employed in all machines whose output does not exceed 170 kw. Among the numerous types which have been constructed for various purposes, we will describe a few of the principal ones.

The bipolar type (Figs. 239 and 240) is constructed for out-

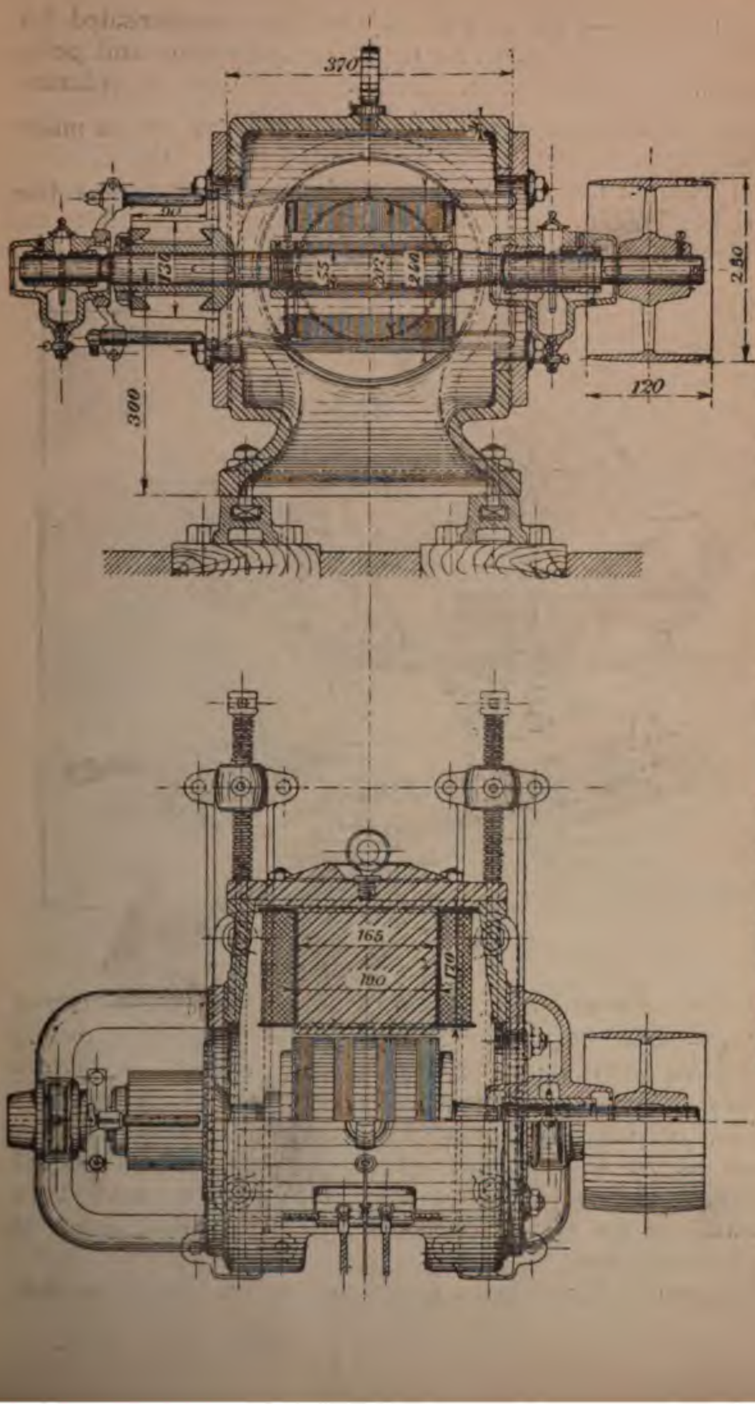


FIG. 240 *a* and *b*.—5 kw. Dynamo at 1,200 revs. per minute, designed by the Author.

puts between 2·5 kw. and 18 kw. The particular form given to this machine is due to its being designed to drive machine tools, cranes, etc. In these cases it is desirable that the motor should occupy as little space as possible on either side. Moreover, care must be taken to protect the windings from external influences. The field magnets comprise only a single bobbin, an arrangement which the author has employed for the last eight years. The asymmetrical field

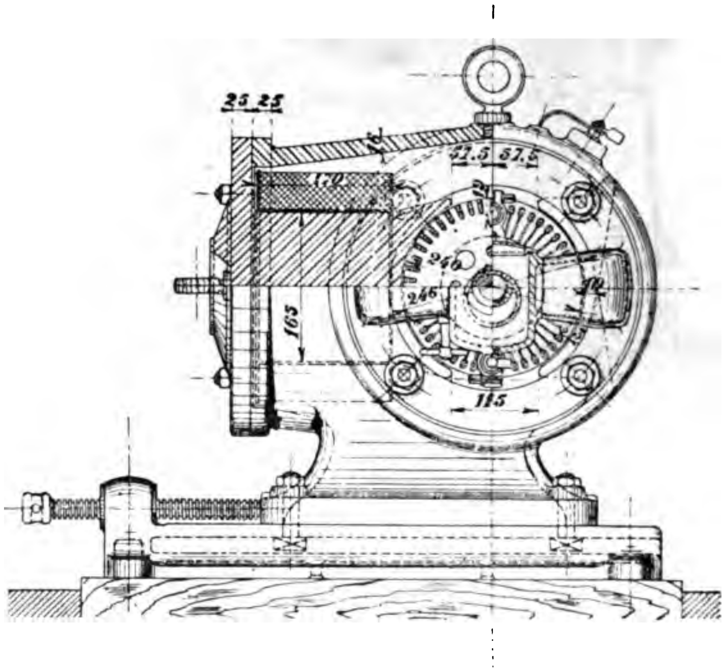


FIG. 240c.

which results is compensated for by a corresponding displacement of the brushes toward one side or the other. Owing to the dimensions and the method of winding chosen, both of which were calculated out with great care, the load on this machine may be increased without displacing the brushes from open circuit to about 20 or 30 per cent. above full load without any sparks whatever being observable.

This absence of sparking is probably due in part to the fact

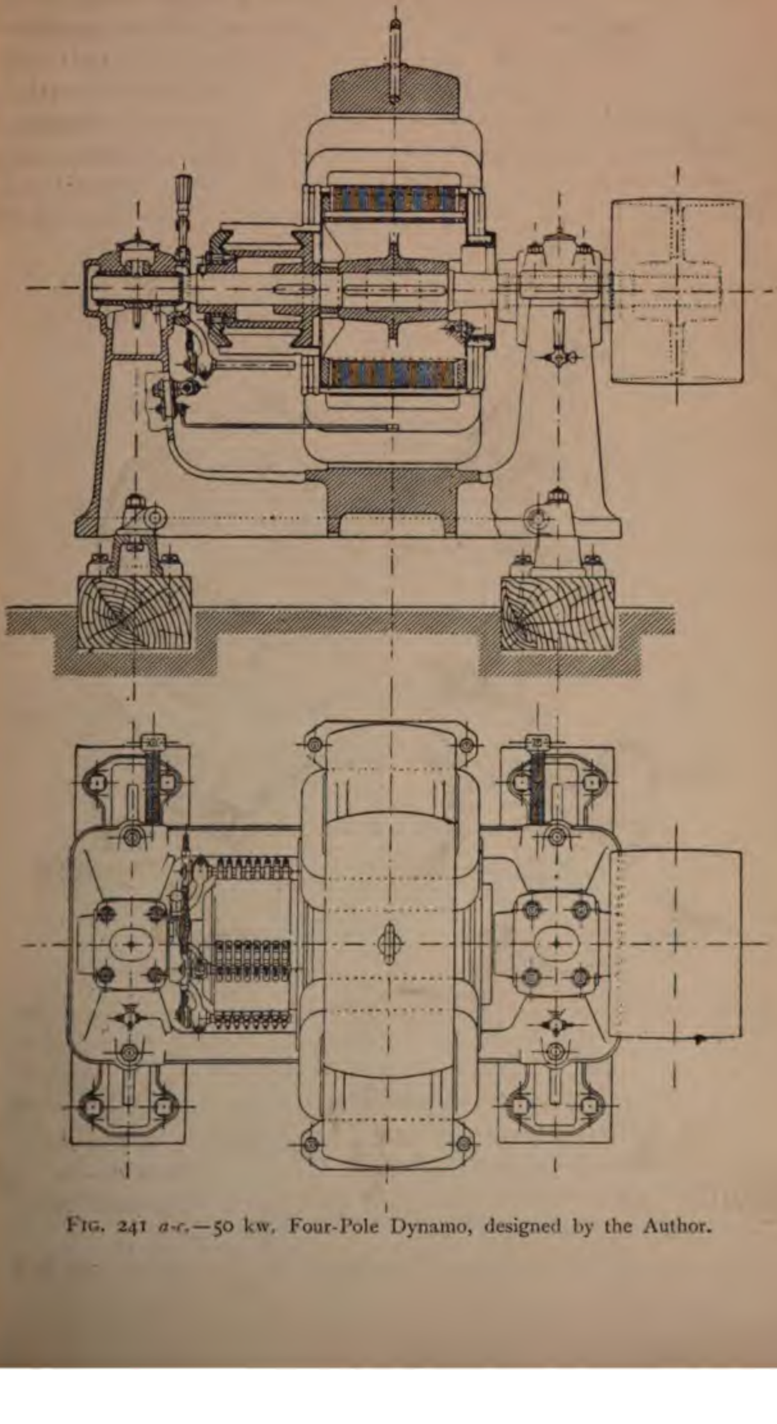


FIG. 241 *a-c.*—50 kw. Four-Pole Dynamo, designed by the Author.

that the wires composing each section of the armature are distributed in several slots (French patent, June 4, 1894). A current of air circulates on all sides of the lateral junctions of the armature wires, and these junctions are easily accessible when it is necessary to repair the machine.

All the windings were executed by the aid of formers.

The more powerful machines, of from 25 kw. to 80 kw., are furnished with four poles. Figs. 241, *a*, *b*, *c*, refer to one of

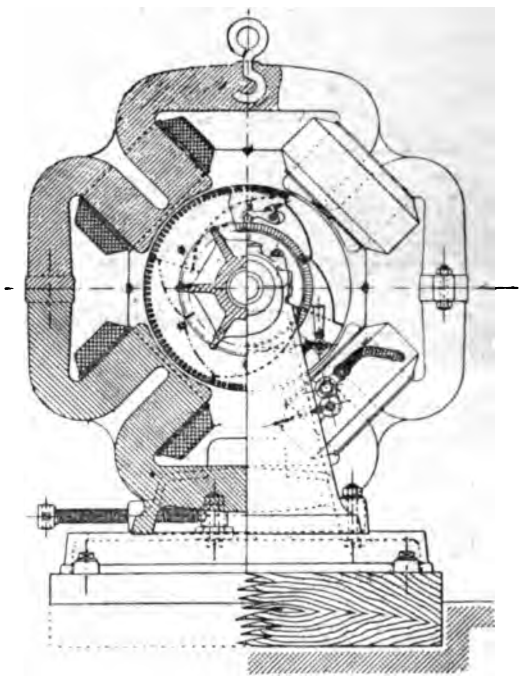


FIG. 241*c*.

these. Let us turn our attention especially to the winding, which consists of copper bars bent at the end of the armature nearest to the pulley; the winding in this case is therefore executed with the use of only a single cross-connection, the other being disposed along a radius (French patent, July 1, 1897). At the end next to the commutator each bar is provided with a soldering. In this manner it is possible to replace any particular insulated bar without interfering

with the rest of the winding, an advantage previously confined to ring windings.

The cast-iron spokes of the armature spider are inserted in the wrought-iron discs so as to act as drivers.

To diminish the transverse induction which is so prejudicial to the good working of a machine, grooves of from 2 cm. to 3·5 cm. deep are cut in the poles.

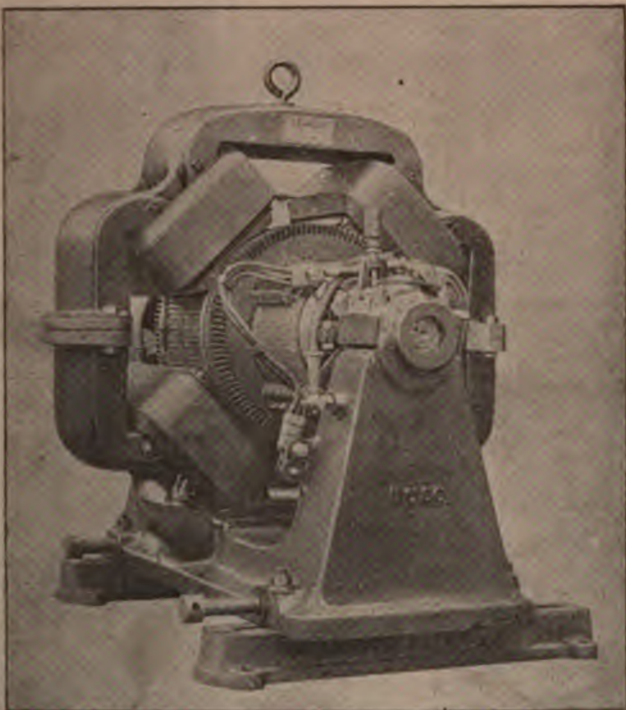


FIG. 242.—Four-Pole Dynamo, designed by the Author.

We have already described the tightening screws (Fig. 226*b*) and the brushes (p. 220) in these machines.

The dynamos made in the Farcot firm, when their output exceeds 100 kw., have six or eight poles; they are provided with a circular yoke of cast iron, provided with field-magnet cores, of circular sections, made from cast steel. We have enumerated in Chapter VIII. the advantages gained by this arrangement.

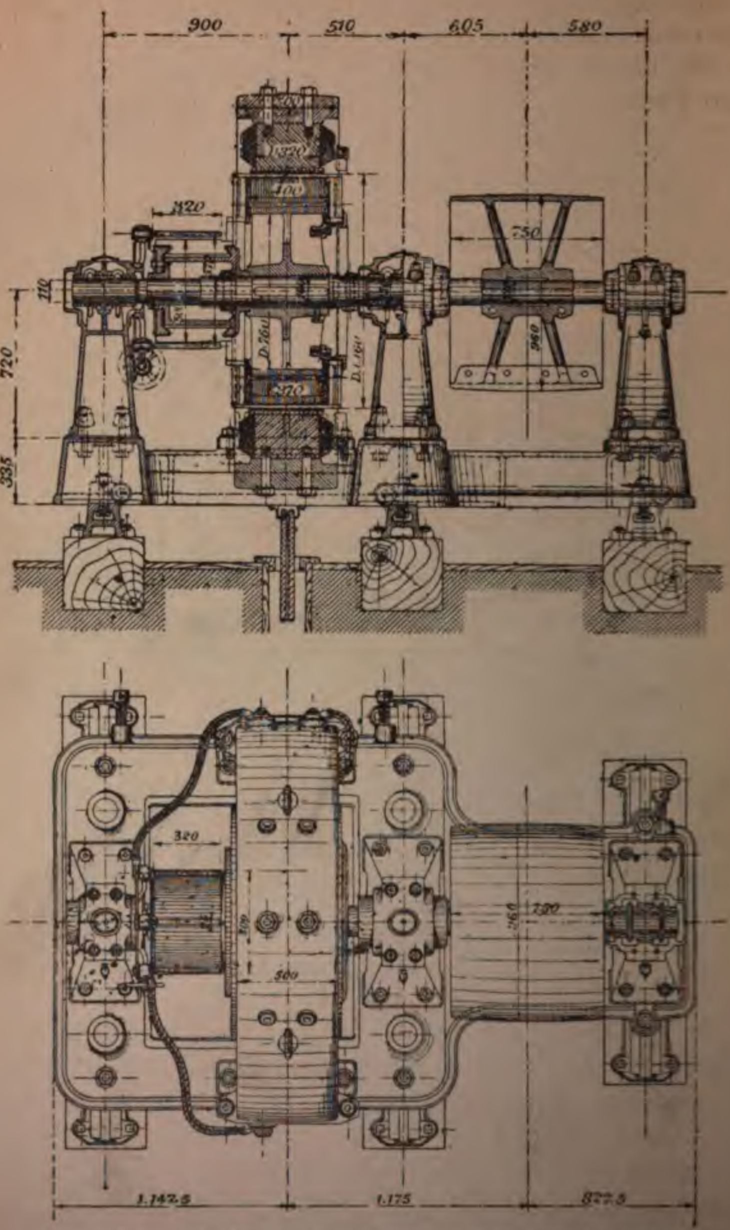


FIG. 243 *a-c*.—170 kw. Six-Pole Dynamo, designed by the Author.

Figs. 243 *a* and *c* show a dynamo of 170 kw. and speed of 360 revolutions per minute ; a dynamo of this type is installed in the bicycle works of MM. Darracq and Co., at Suresnes, near Paris.

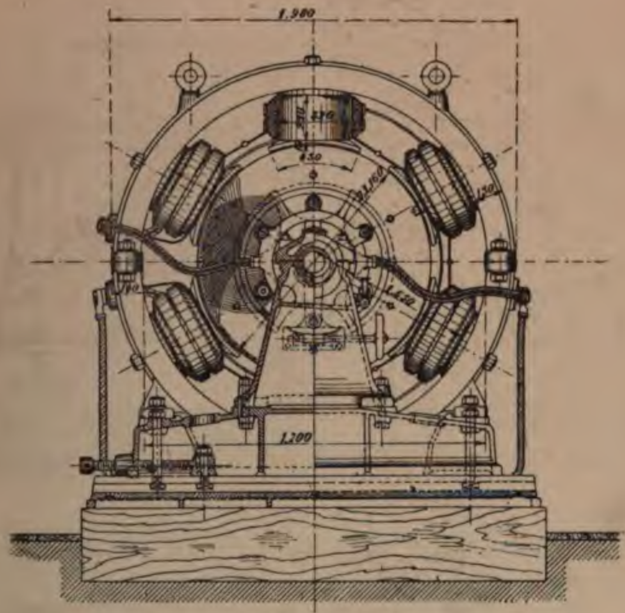


FIG. 243*c*.

Fig. 244 gives a photographic view of the dynamo.

The following data refer to this machine :

D = 116 cm. l = 40 cm.
N = 216
C = 1,360. E = 125 volts.

The machine is worked on the Farcot system, by a single-cylinder Corliss engine, to which the following data refer :

Diameter of cylinder = 515 mm.
Length of stroke = 1,150 mm.
Speed = 72.

We will mention a few other dynamos constructed in these works.

Figs. 245 *a* and *b* show a continuous-current dynamo of

600 h.p., designed to be coupled directly to the engine; the speed is 60 revolutions per minute.

As it was necessary in this case that only one bearing should be provided, the armature was arranged as shown in Fig. 245*b*.

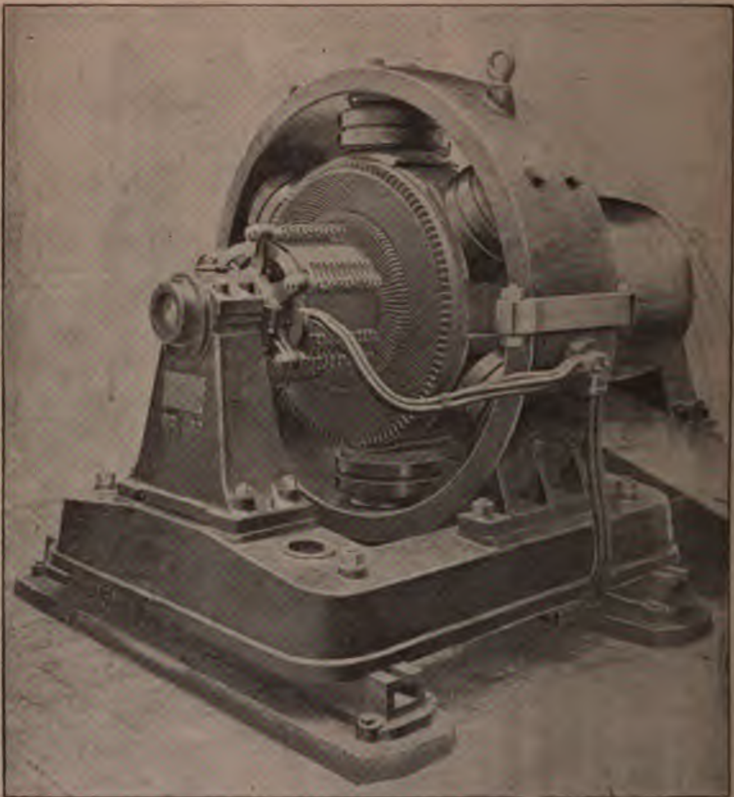


FIG. 244.—170 kw. Dynamo, designed by the Author.

The elastic foundations must be made with the greatest care, since vibrations will tend to alter the air-space at each stroke of the piston, and thus to give rise to magnetic tractive forces of considerable magnitude. This difficulty has been overcome, in the dynamo at present under consideration, by rendering the magnetic traction constant whatever may be the position of the armature.

The armature is wound according to the Arnold system,

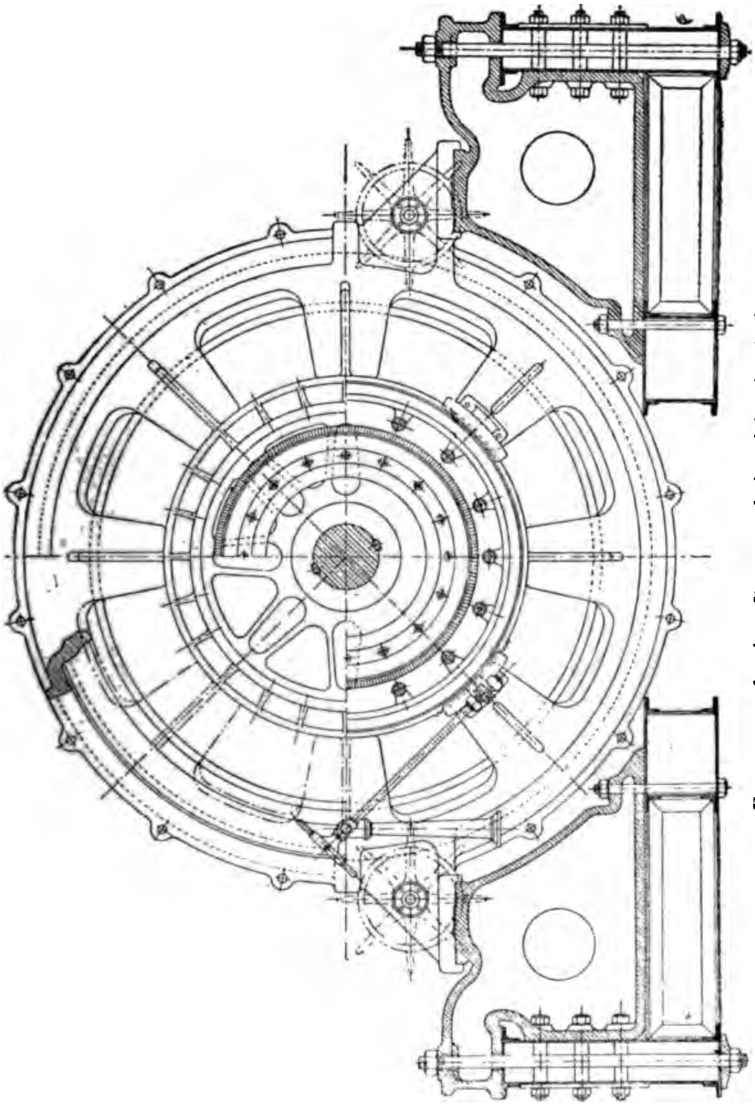


FIG. 245*a*.—600 h.p. Dynamo, designed by the Author.

and the field magnets are furnished with a single bobbin (see "Die Ankerwicklungen und Ankerkonstruktionen," Arnold: Berlin, 1891).

In the vertical motor (Fig. 246 *a* and *c*), which was designed to work a pump, the weight of the latter, as well as that of the shaft, is supported by a collar, assisted by a magnetic compensator.

In certain machines constructed after this type it has been found necessary to vary the speed between wide limits. Use is then made of motors with two windings, the armatures being

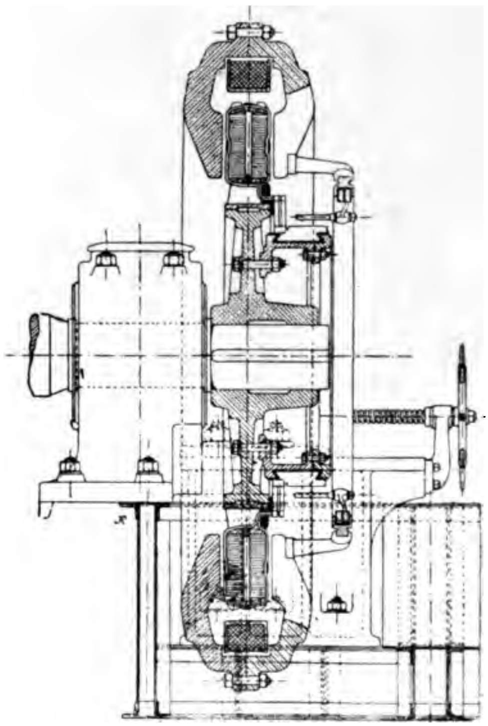


FIG. 245*b*.—600 h.p. Dynamo, designed by the Author.

connected, according to the requirements of the case, in series or in parallel.

Lastly, we will mention a small dynamo of 400 amperes, destined to be used for purposes connected with electrolysis (Fig. 247 *a* and *b*). This machine is provided with the compensating winding invented by the author in 1890. Tests have shown that it is able to work for some hours at three times the normal load without the least sparking at the brushes.

The establishment of *Bréguet*, at Paris, is counted amongst the most ancient dynamo works in France;

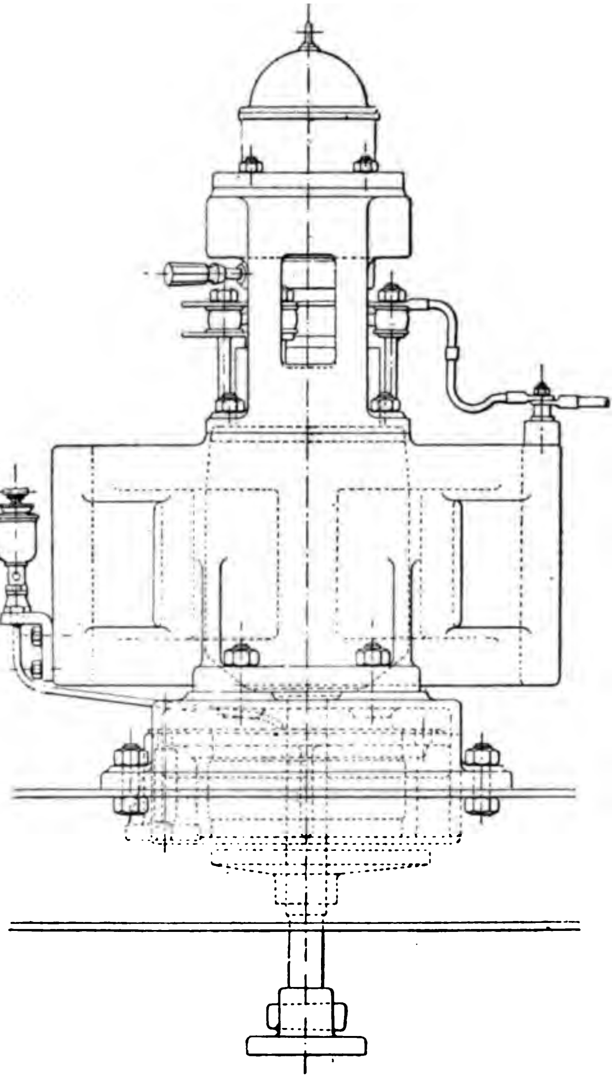


FIG. 246*a*.

this firm, as well as that of Farcot, at Saint-Ouen, manufacture only those types of machines which properly

belong to them. Amongst the dynamos constructed by Bréguet we have already mentioned the Desroziers con-

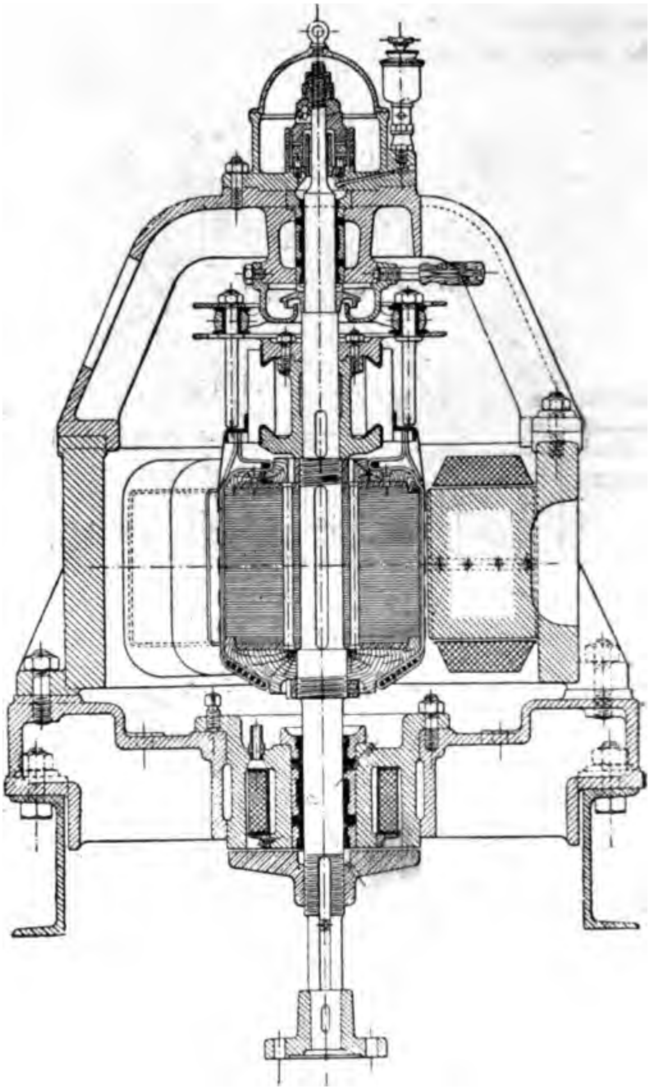


FIG. 246*b*.

tinuous-current dynamo furnished with a disc armature. *This type* of machine is mostly employed when it is

necessary that the dynamo should be coupled directly to a steam-engine; it works well provided the foundations are solid. That which strikes us in these machines is their extreme lightness. However, it should not be forgotten that the weight of copper is much greater in this than in

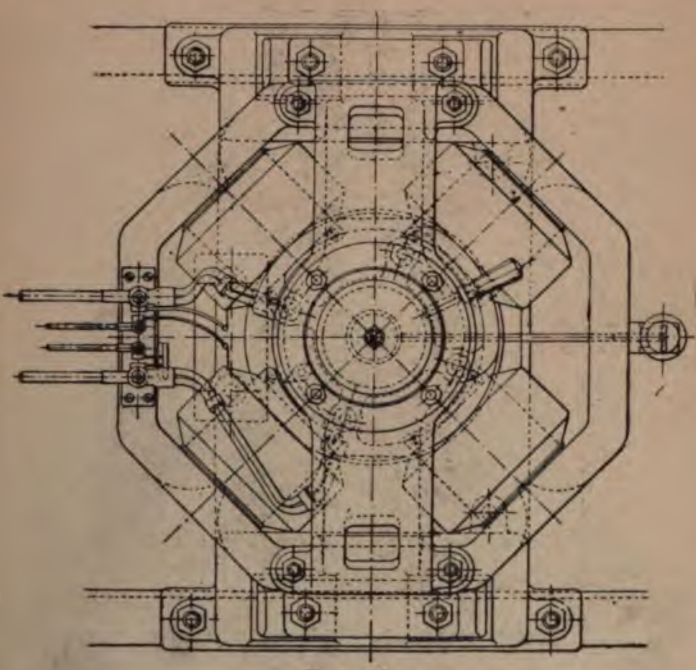


FIG. 246c.

other types, on account of the great air-gap. If we calculate the total weight of a dynamo from the formula

$$\text{Weight} = c\left(\frac{\text{output in watts}}{\text{speed}}\right)^{\frac{2}{3}},$$

the coefficient c is comprised between 120 and 140 for Desroziers dynamos, whilst it attains in other machines a value of 160 to 170, and even 200.

Besides disc dynamos, the firm of Bréguet construct a great number of other continuous-current machines, which are destined for ordinary employments or for special purposes.

Figs. 248 a and b illustrate a small bipolar motor, with

a single field-magnet bobbin. One of the journals is made from cast iron similar to that employed for the base, the other is of bronze. The armature is of the ordinary Gramme ring type; this form is often employed in France.

FIG. 247a.—Dynamo for High Amperage, designed by the Author.

Another dynamo, designed to be coupled directly to a steam-engine, is shown in Figs. 249 *a-c*. The yoke for the field magnets is in two pieces; four poles with two exciting coils are used. To reduce the number of brushes to two the ring armature is wound in series, the different sections being joined by means of cross-connections on the commutator.

The following are some data in connection with this dynamo.

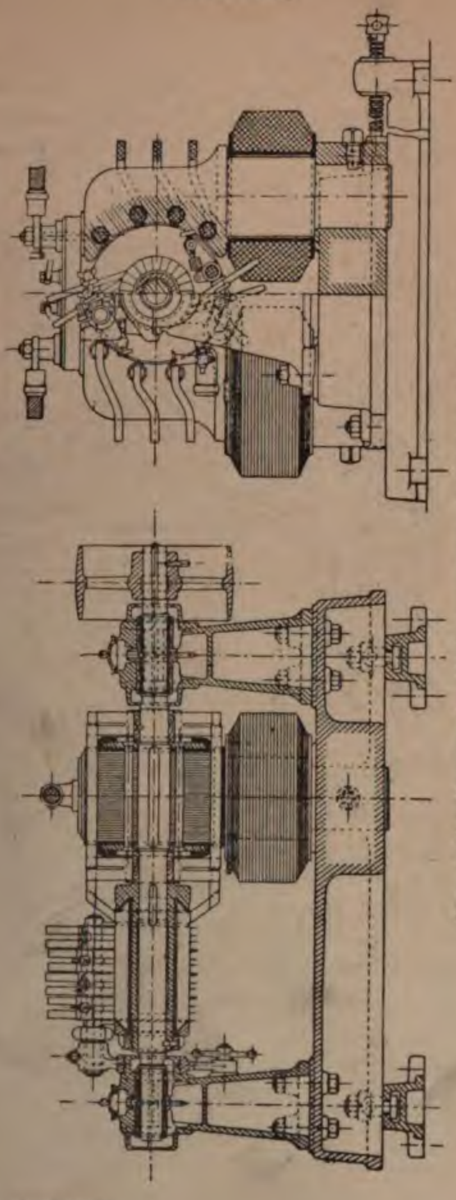


FIG. 247*b*.—Dynamo for High Amperage, designed by the Author.

$C = 300$ amperes.
$E = 82$ volts.
$n = 350$.
$D = 52$ cm. $D_1 = 38$ cm. $l = 30$ cm. $\delta = 2$ cm.

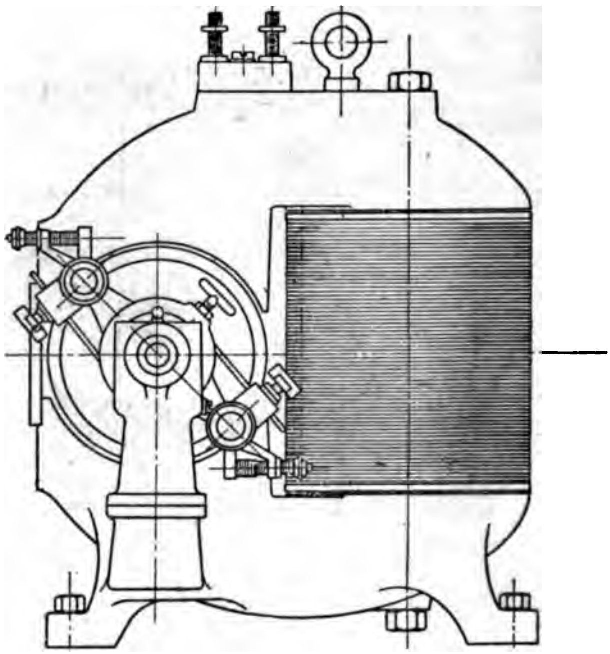


FIG. 248a.

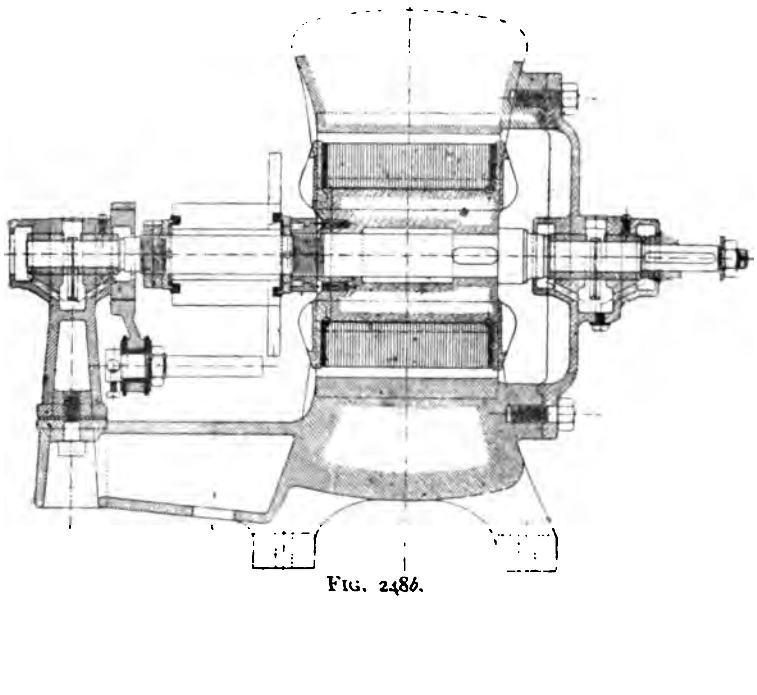


FIG. 248b.

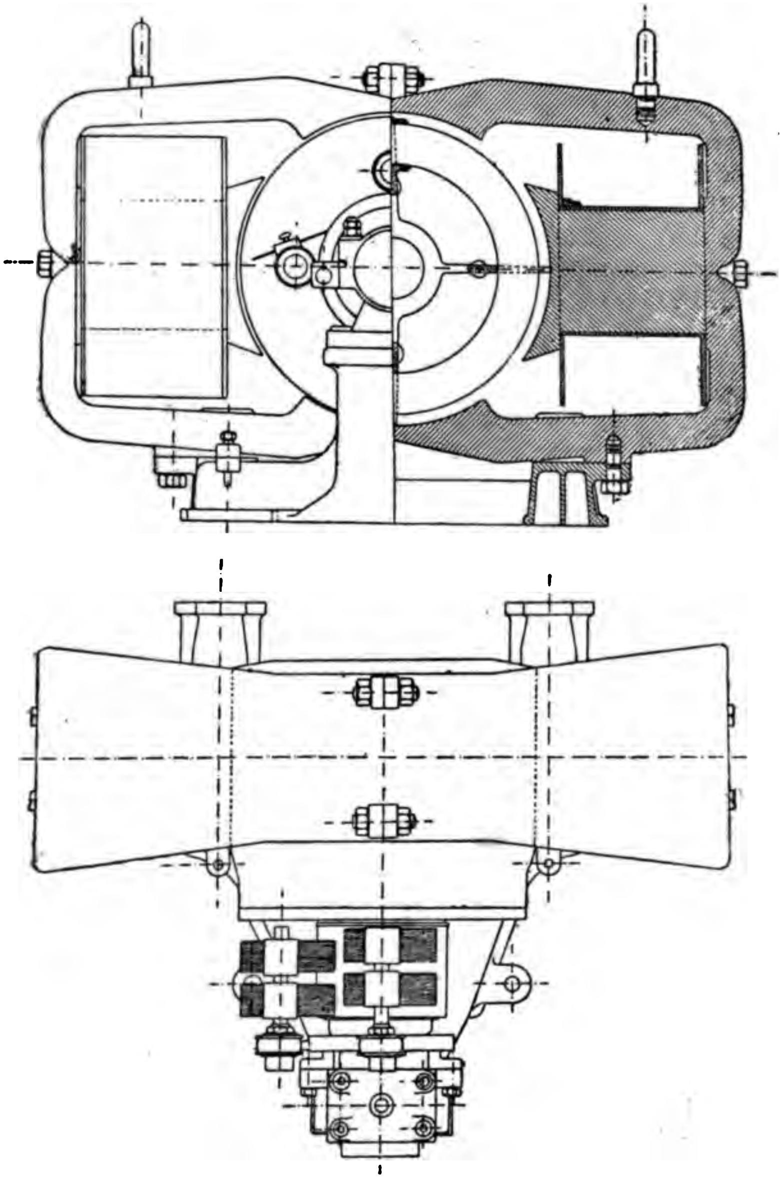


FIG. 249 *a* and *b*.—25kw. Bréguet Dynamo.

All dynamos made by the firm of Bréguet are furnished with ring armatures when the output is not greater than

22 kw.; with a greater output either drum or ring windings are employed, according to circumstances.

The *Compagnie de Fives-Lille* works the patents of the *Allgemeine Elektricitäts-Gesellschaft*, of Berlin.

Amongst the important installations designed by this firm we will mention only the Edison station at the faubourg Montmartre. This installation is particularly interesting, since the generator is designed for the system of distribution by means of three wires, described on p. 253 (see the article by M. P. Girault, *Eclairage Electrique*, Jan. 29, 1898).

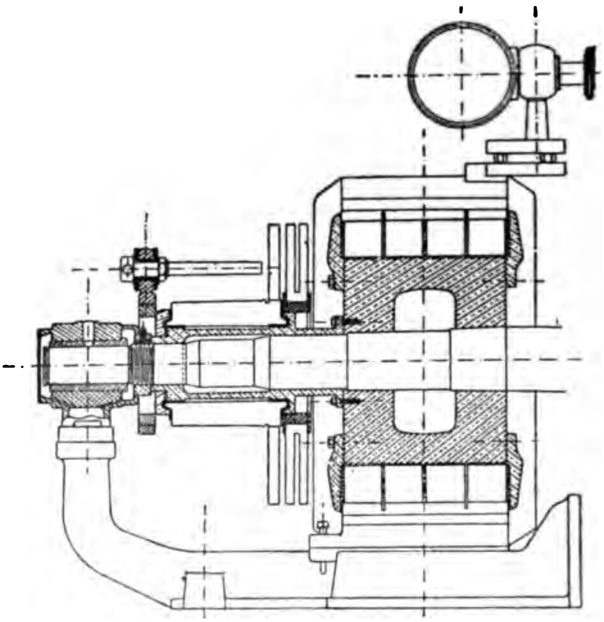


FIG. 249*c*.

This dynamo (Fig. 250, *a-c*) can furnish a current of 1,330 amperes at a pressure of 2 × 150 volts, its speed being 300 revolutions per minute.

The following data apply to this machine:

Armature (with slots nearly closed)—

$D = 173$ cm. $D_1 = 120$ cm. $l = 45$ cm.

$N = 400$ (Mordey winding).

$p = p_1 = 5$.

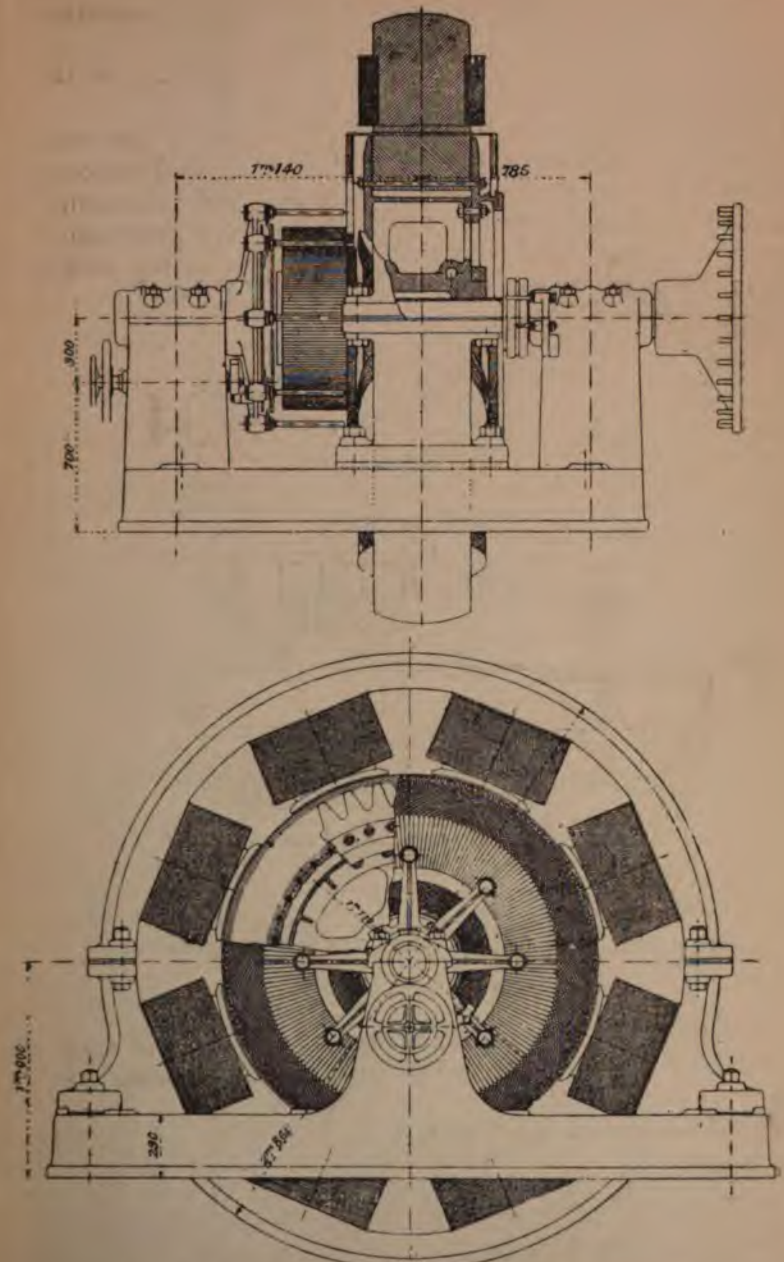


FIG. 250 *a* and *b*.—Fives-Lille Company 400kw. Generator.

$$\phi = \text{about } \frac{(290 + 20) \times 60 \times 10^8}{400 \times 300} = 15{,}500{,}000.$$

The conductors, reuniting the middle points of the various cross-connections with the appropriate commutator sections, are made from bands of nickeline, so as to introduce a certain resistance into the bobbin which is being commutated. Although this supplementary resistance (Fig. 250) is relatively large when compared with that of a single armature section, it is yet small when compared with the resistance of the whole armature.

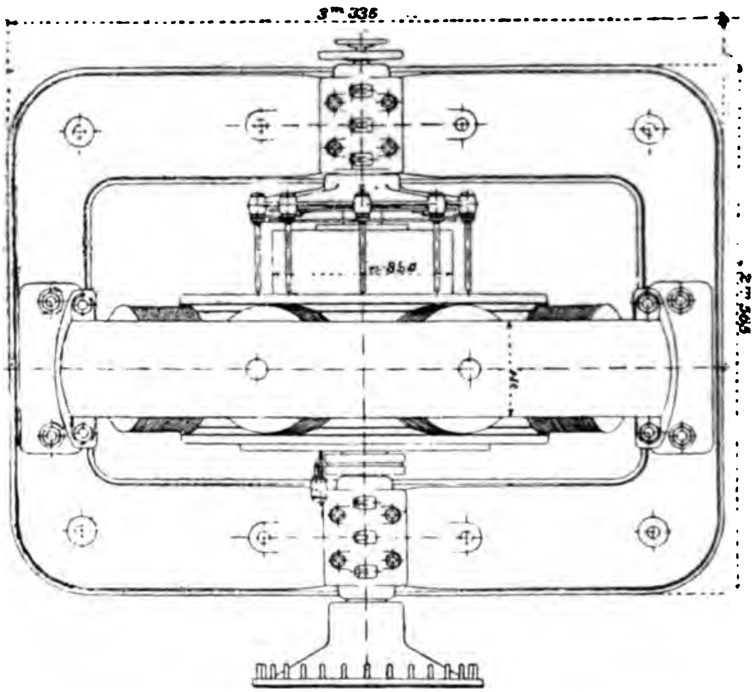


FIG. 250c.

Field magnets: Resistance of eight bobbins in series = 4'
The body of the machine is in Robert steel.

The equalising bobbin (see Figs. 251 *a* and *b*), w resembles an old Zipernowski transformer, is compose a hub formed from circular discs of sheet iron cla ··ther by means of insulated bolts.

L. Couffinhal (Saint-Etienne).—In the Couffinhal machine (Fig. 252 *a* and *b*) the transverse induction is almost com-

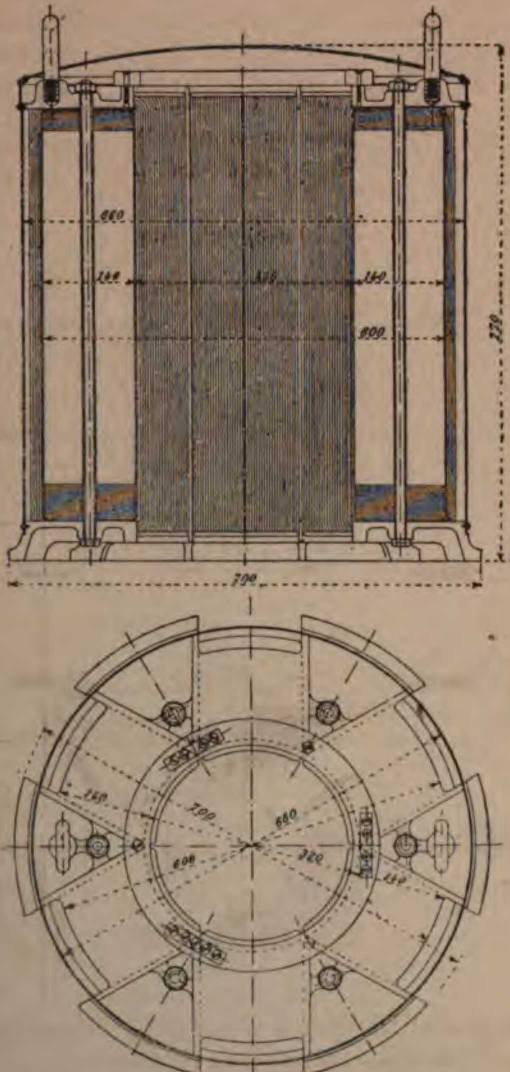


FIG. 251 *a* and *b*.—Fives-Lille Compensation Coil.

pletely suppressed by the aid of divisions in the poles (see Fig. 142). The bearings each possess two lubricating rings.

Allmanna Svenska Elektriska Bolaget (Wenström Company), now at Vesteras (Sweden).—This company has patented a large number of remarkable inventions relating to applications

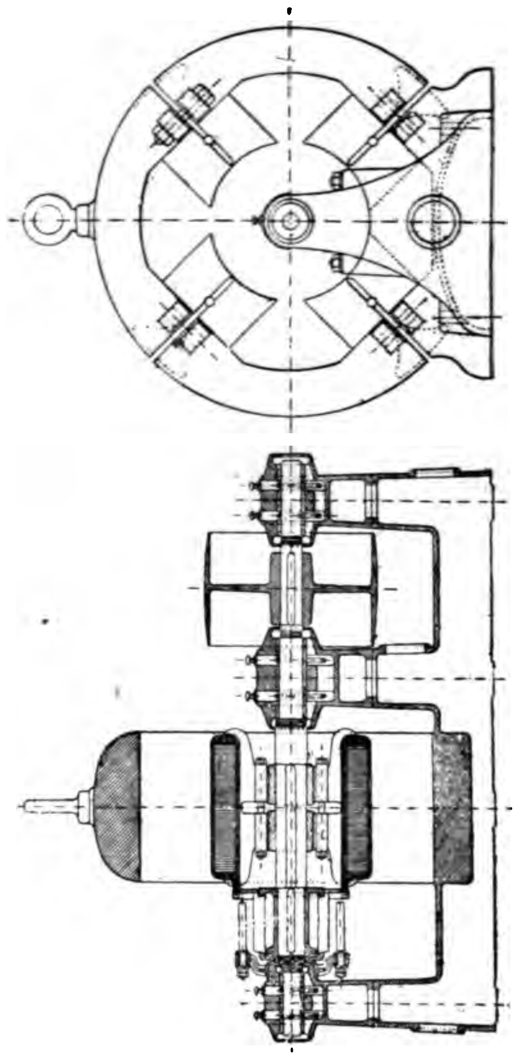


FIG. 252 *a* and *b*.—Four-pole Dynamo built by M. L. Couffinhal.

of electricity. It is well known that Jonas Wenström was one of the first electricians to study the subject of electric traction in connection with the use of dynamos with revolving

fields. That engineer was also the first to construct a dynamo entirely enclosed in iron, as well as armatures with tunnels for the conductors. We might further consider him as the inventor of field magnets with a single central bobbin (Plate II., Fig. 36), which play such an important part in the construction of alternators. (See an article by Rob. Dahlander in the *Teknisk Tidskrift*, Stockholm, 1896, and *Lumière Electrique*, vol. ii., p. 21, 1886.)

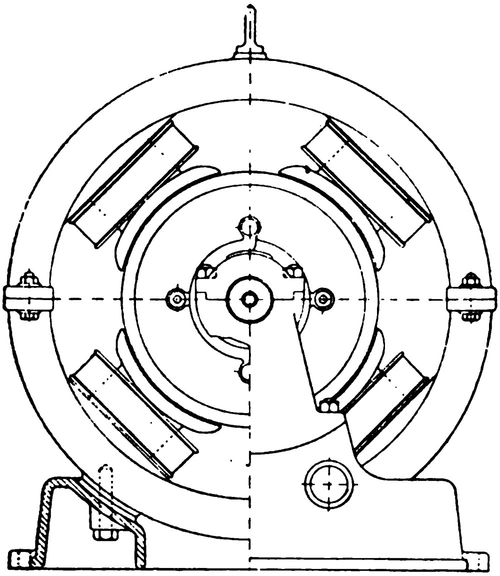


FIG. 253*a*.

Fig. 23, Plate II., shows a form of machine formerly made by this firm, but now abandoned. Figs. 253 and 254 of the text represent two more recent patterns. The first of these dynamos has an output of 115 h.p., and has a speed of 435. The second has an output of 320 h.p., and a speed of 235. The circular yoke as well as the cores of the field magnets are made from cast steel; the pole-pieces, which are bolted on to the cores, are of cast iron.

The tendency, which we have already remarked in the Alioth dynamos, to carefully work all the bearing surfaces is equally manifest in this machine. On the construction of the bearings great care is bestowed; each of these is

provided with two lubricating rings, and, in its midst, with a spherical bush. Similarly, the brush-holders are carefully

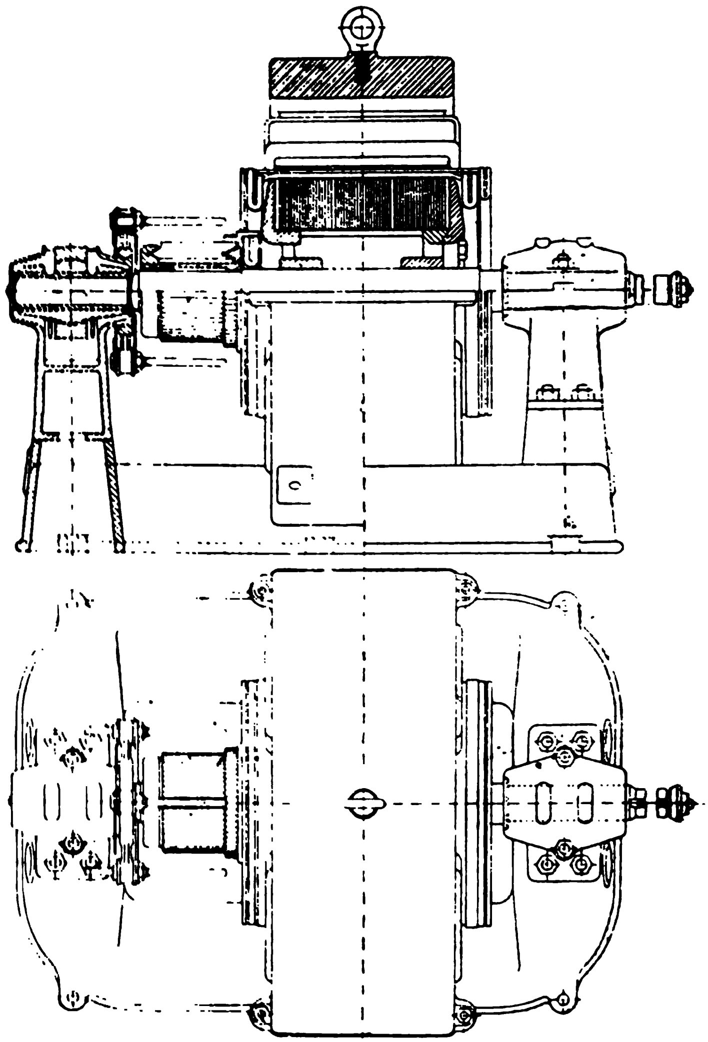


FIG. 253 *b* and *c*.—Wenstrom Company Four-Pole Dynamo.

and solidly made. The tunnelled armature is furnished, beside the principal windings, with a Sayers compensating winding (see p. 42). Thanks to this arrangement, when

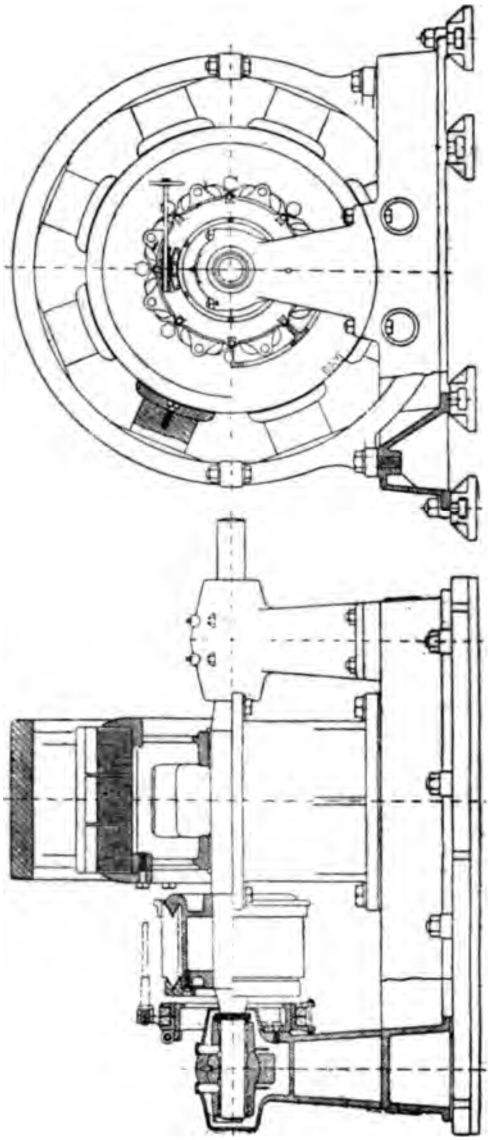
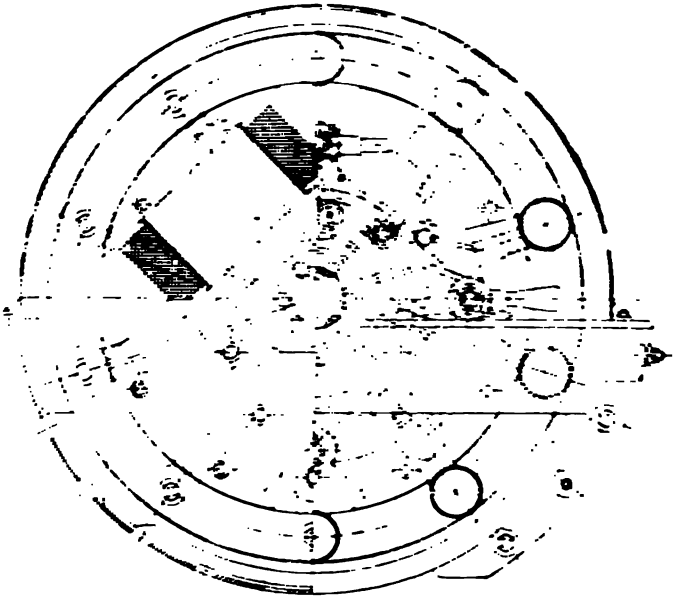


FIG. 254 *a* and *b*.—Wenstrom Company Eight-Pole Dynamo.

the machine is working under full load, or even when it is overloaded, no sparking is produced, and no displacement of the brushes is necessary.

[illegible] — [illegible] already alluded in [illegible] design due to [illegible] self-induction. [illegible] Of all the continuous-current machines [illegible] more widely [illegible] as type J. [illegible] of the armature. This type of machine is well adapted to be directly coupled to a steam-engine, and possesses great advantages both from its compactness and its lightness. The reason of this is



[illegible]

that the armature is used under the most advantageous conditions, and that thus both the length of path of the lines of force and the weight of copper in the armature are reduced to their minimum values. It only remains to be said that the restricted space to be disposed of for winding generally necessitates the use of cast steel in the magnetic circuit, thus leading to a great reduction in the weight of the machine.

As this dynamo is generally designed to be coupled directly with a steam-engine, a special base-plate is unnecessary, and

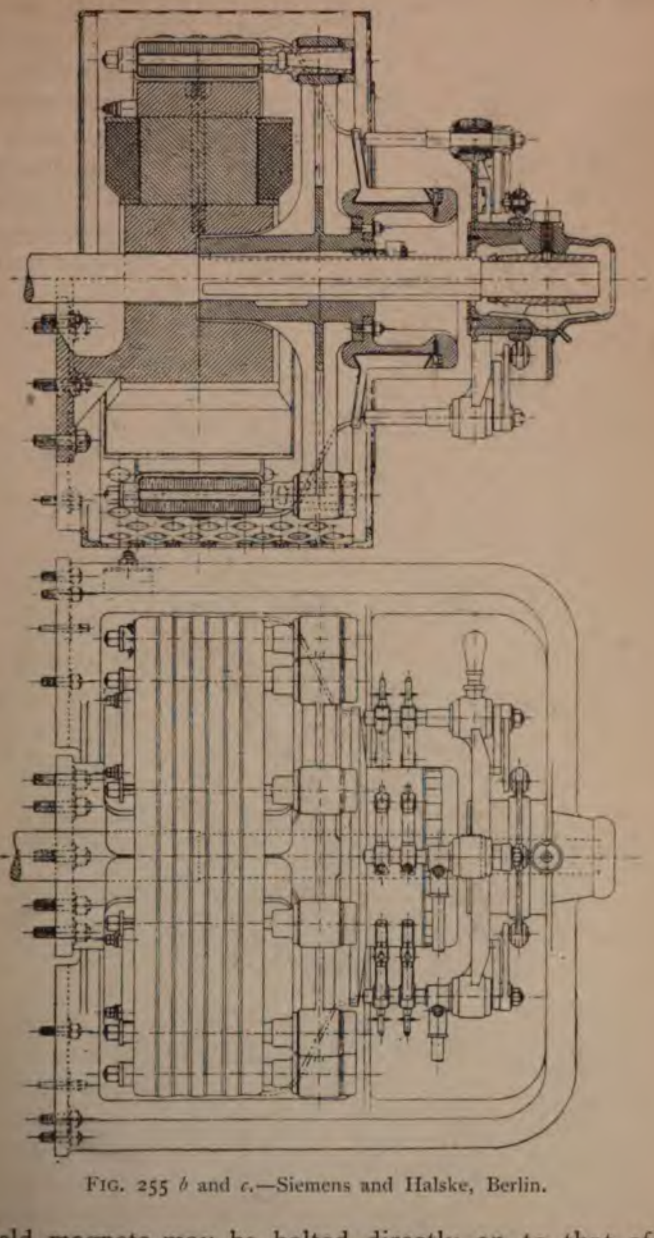


FIG. 255 *b* and *c*.—Siemens and Halske, Berlin.

the field magnets may be bolted directly on to that of the engine.

Messrs. Siemens and Halske construct this type of dynam
under two forms: (1) with a special form of commutato

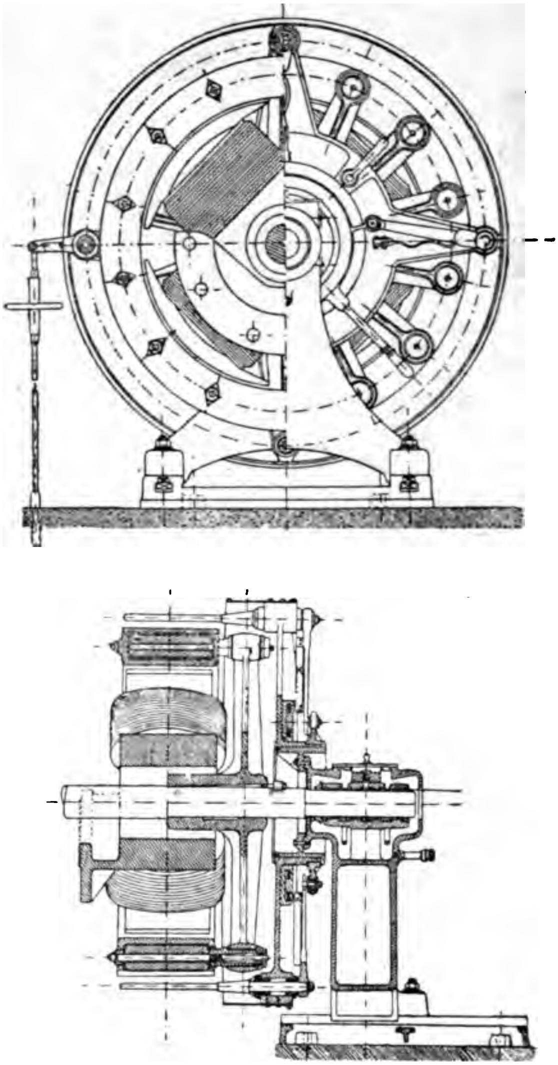


FIG. 256 *a* and *b*.—Société Alsacienne, Belfort.

such as that shown in Fig. 255; (2) without this specia
form of commutator, as shown in Fig. 256. In this latte

case the brushes rub directly on the external surface of the armature windings.

In the dynamo of small output (Fig. 255), which is well adapted for service on board ship, the external bearing is overhanging, and constitutes at the same time a protection for the armature. The discs of which the latter is constructed are maintained in position by means of ten insulated bolts, which are furnished at one of their extremities with bronze sockets bolted on to the ten spokes of the armature spider. These bronze sockets are so arranged that the iron of the armature is insulated from the cast-iron spokes of the spider.

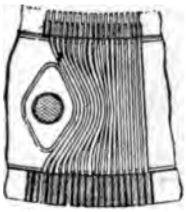


FIG. 257.

We have already mentioned (Chapter VIII.) the particular construction of the commutator. Connection between the lines of brushes of the same sign is effected by means of copper bars placed between wooden boards. It may be added that all the machines are furnished with an arrangement by means of which the brushes may be raised on starting or stopping the steam-engine; all possibility of injury to the brushes, should the engine start in the wrong direction, is thus avoided.

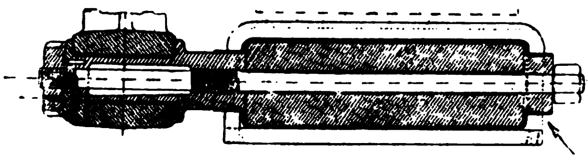


FIG. 258.

Figs. 256 to 258 show different views and details of a 96-kw. machine with interior poles, constructed at the works of the *Société Alsacienne de Constructions Méchaniques* at Belfort, which has acquired the French patents of the Siemens and Halske machines. This dynamo is not furnished with a special commutator.

The following data refer to this machine :—

$$E = 275. \quad C = 350. \quad n = 210.$$

Armature (14 bolts of 2·3 cm. diameter):

$D = 138$ cm. $l = 35$ cm.

$D_1 = 117$ cm.

$N = 840$.

$s = 100$ sq. mm. at the circumference and 45 sq. mm. for the interior winding.

Resistance between two consecutive brushes = 0·016 ω.

$\phi = 10,000,000$.

$B_a = 15,600$.

Field magnets (in cast steel):

$S_l = 75 \times 35$ sq. cm.

$\delta = 3$ cm.

Resistance = 42 ω.

The great advantages possessed by this type of machine (with interior poles) have led to its adoption by several German firms, amongst others by *Messrs. Naglo Bros.*, of Berlin, and *Messrs. C. and E. Fein*, at Stuttgart. It is probable that this type of machine was first constructed by *Messrs. Ganz and Co.*, of Budapest, who subsequently abandoned it (see *Lumière Electrique*, 1887, vol. ii., p. 182).

The dynamo of which we have spoken, in which the brushes rub on the external surface of the armature conductors, would appear at first sight to be open to grave objections relating to the above-mentioned structural detail. But it appears that such objections are not well founded; experience during the last 10 years has completely refuted them. This may partly be explained by the excellence of the work bestowed on these machines. Further, it is evident that the peripheral speed of the armature conductors in this machine is not much greater than that of the surface of the commutators in others, therefore no greater wear need be anticipated in this than in other cases. We will mention finally a small bipolar dynamo of the type 4 H 5 with a drum winding (Fig. 259). The following data refer to this machine:

$E = 150$.

$C = 25$.

$n = 1,050$.

$D = 18$ cm. $l = 20$ cm.

$N = 960$, distributed between 40 slots ($N_1 = 40$).

$N_2 = 20$.

In addition to the special details of the commutator already described (p. 296), it may be mentioned that the sections are interchangeable. To preserve the armature from external influences, it is enclosed in a suitable cage.

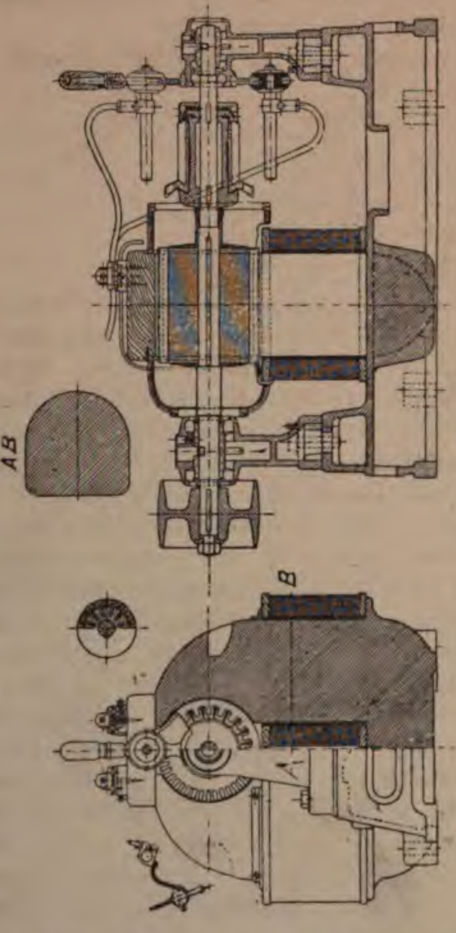


FIG. 259.

Elektricitäts Aktien-Gesellschaft, vormals Schuckert und Co.—The first dynamo with a flat ring armature and lateral poles was probably constructed in the workshops of this company (1876). Although other forms of dynamos are constructed by them, those with flat ring armatures constitute the speciality of the firm. As is well known, these machines

present the advantage that the air-space between the core of the armature and the poles is not modified when the shaft bends. Further, the space occupied by the field magnets and their yokes is smaller than in other machines, and the construction of the armature core is considerably simplified. This advantage is, however, counterbalanced by the high price of the iron ribbon, which is often 30 cm. broad: the price of the ribbon being 4d. per lb., whilst that of the ordinary discs is $1\frac{3}{4}$d. to $2\frac{1}{4}$d. per lb. Moreover, it becomes difficult to obtain ribbons of a sufficient length when the machines exceed a certain size, and in all cases the quality of the iron, as far as relates to hysteresis losses, is much inferior to that generally used in the construction of armatures.

In flat ring armatures the Gramme winding is employed. Figs. 260 *a-c* are drawings of the type J L 18 for direct coupling with an engine. The dynamo in question is placed in the generating works at Hanover.

The following are data referring to this machine:

- E = 250 volts; C = 1,600 amperes; speed = 110 revolutions per minute.
- Number of poles = 14; number of brushes = 6 (Mordey winding).
- Mean diameter of armature - 260 cm.; height of iron = 50 cm.
- Width of iron = 19·6 cm.; number of wires = about 1,120.
- Number of commutator sections = 1,120

Fritsche and Pischon (Berlin).—The machines constructed by this firm are characterised, without exception, by their originality. Perhaps the best known of these is the dynamo with a "wheel armature," a name given to a particular form of disc armature.

The idea of a disc armature is by no means novel, since Paccinotti, in 1875, designed a machine possessing an armature of this class. Since that time a large number of patents for improvements have been applied for by Messrs. Jehl and Rupp, Edison and Desroziers, to mention only the better known inventors. The disc armature presents, in comparison with an ordinary armature, the great advantage that the iron core is abolished, thus materially decreasing the *total* weight of the machine. But all the types due to the

just mentioned inventors have the disadvantage of great want of solidity and strength; to which must be added the considerable weight of the copper in the field-magnet windings, owing to the great magnetic resistance of the air-gap. The above faults, which have up to the present been very prejudicial to the use of armatures of this kind,

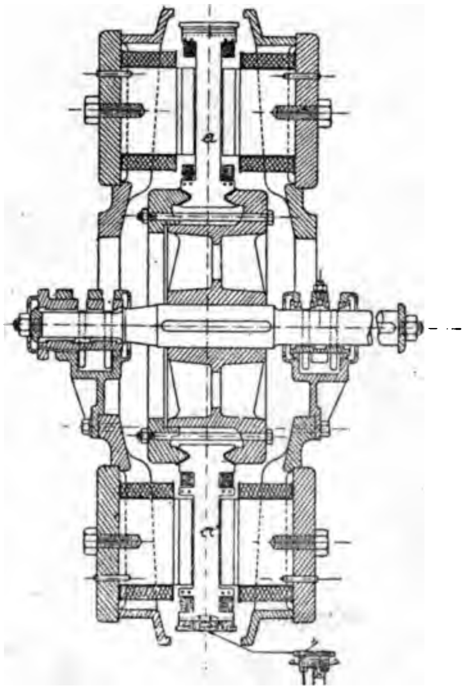


FIG. 261*a*.

have been entirely suppressed in the Fritsche dynamo by the use of an ingenious arrangement which permits of these machines being so constructed as to compare favourably with dynamos of ordinary types.

The characteristic of the Fritsche dynamo consists in the wheel-like shape of the armature, the conductors forming the spokes, whilst the rim is formed by the commutator (German patent No. 57,170, April 16, 1890). But, while in the previously-mentioned disc armatures the windings are always disposed in two planes, thus necessitating a wide air-gap, the

windings of Fritsche's' machine are all situated in a single plane. The scheme of winding differs in no essential particular from that of an ordinary drum winding. We can form some picture of it by supposing that those armature wires, which in ordinary windings are in a plane perpendicular to that of the paper (Fig. 261*b*), are here disposed along the radii, and

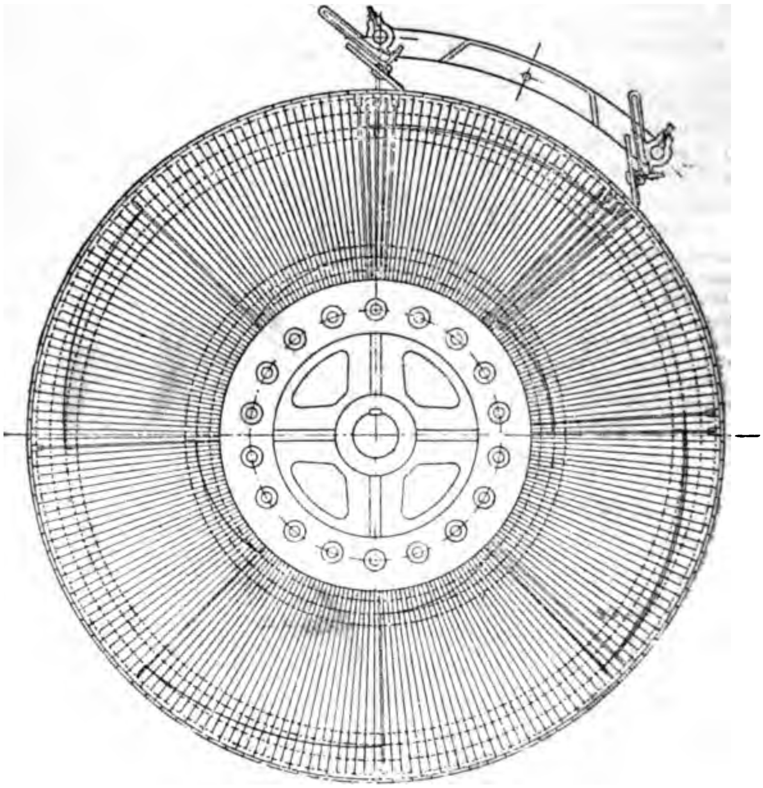


FIG. 261*b*.

that the connections at the further end of the armature are now made on the circumference of the armature. The radial bars are wholly or partly made of iron so as to diminish the magnetic resistance between the poles. The connections between the bars are effected by means of thin ribbons of insulated copper, riveted or soldered to the bars. The odd radial bars terminate on a brass bar, *a* (Fig. 261*a*), which

is bolted to a commutator section; the even bars are maintained in position by the insulated pieces, *c*, which are screwed between them. In the following table some information is given as to dynamos with wheel armatures.

Type.	M.	CL.	C.
Volts	240	220	120
Amperes	270	160	180
Speed	135	130	180
External diameter of armature	1,880 mm.	—	1,100 mm.
Length of commutator	230	—	—
Height of poles	210	—	—
Distance between poles	90	—	—
Number of poles	10	—	8
Number of conducting bars	522	742, of which half are of iron	398
Dimensions of conducting bars	Thickness $= 2 \times 15$ Length 80	Thickness 3×60 for the iron Thickness $1{\cdot}5 \times 30$ for the copper	
Dimensions of junctions	$60 \times 0{\cdot}8$	—	—
Resistance of armature	$0{\cdot}042\ \omega$	$0{\cdot}0707\ \omega$	—
Resistance of field-magnet windings	39·936	20·58	—
Insulation resistance of armature; Insulation resistance of field-magnet windings	11 megohms	11 megohms	—
Heating of armature	22·5° C.	17° C.	—
Heating of field magnets	10° C.	21° C.	—
Net weight of armature	2,250 kgrm.	680 kgrm.	560 kgrm.
Net weight of the complete machine	6,600 kgrm.	2,900 kgrm.	2,700 kgrm.

Another original arrangement is that of the bell armature of Fritsche, of which Fig. 262 gives some particulars (German patent No. 78,075, May 20, 1893). All the poles around the periphery of the machine have the same sign.

The excitation is maintained by means of a single bobbin. The armature coils, *b*, are constructed with the aid of a former, and are maintained in position by the cap, *c*. To diminish the resistance of the air, the iron bars, *a*, are added, and the commutator sections are placed against these. Lastly, the ring *d* is destined to keep these in position against the action of the centrifugal force generated during revolution.

In considering English dynamos, a noticeable predilection may be observed for bipolar machines of the horseshoe type, arranged sometimes with the opening between the poles uppermost, sometimes with this arrangement reversed (Edison and

Hopkinson). This predilection may certainly be explained by the low cost of materials in England, which permits of the use of the above forms even in large machines.

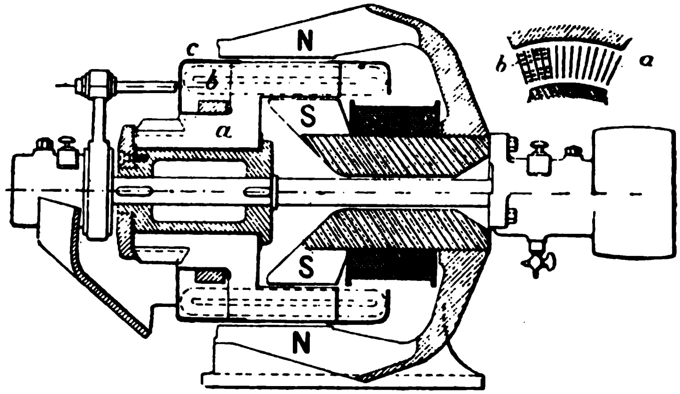


FIG. 262.

Messrs. Easton, Anderson, and Co., of Erith (to whom Mr. V. A. Fynn is the chief engineer), is the only firm in England confined to the construction of multipolar machines.

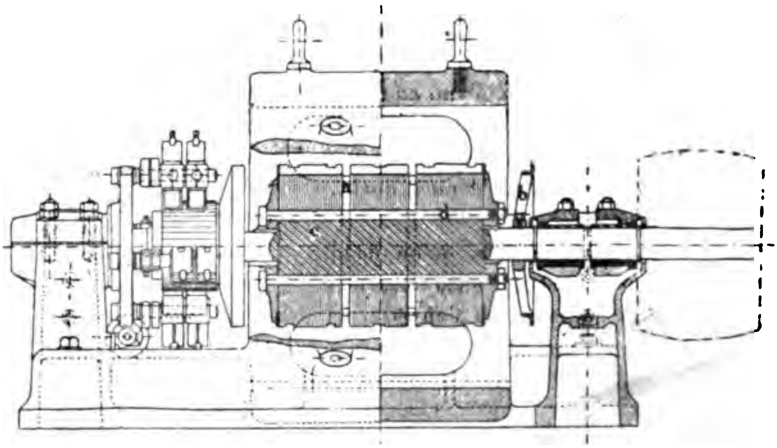


FIG. 263*a*.

The types shown in Figs. 263 *a*, *b*, and 264, range from an output of 0·75 kw. at 2,500 revolutions per minute to 110 kw. at a speed of 600. Four poles are employed up to 110 kw.:

between 110 kw. and 120 kw., six poles are used; for larger outputs eight and more poles are used.

The four-pole dynamo is represented in Fig. 263, which represents a dynamo of 50 kw. The winding is disposed along cylindrical surface of the armature; and the discs composing the latter are maintained in position by means of two auxiliary spiders. The bearings, lubricated by means of chains, present a special interest; the shaft provided with longitudinal ridges may also be noticed. The latter could hardly be procured on the Continent without much trouble.

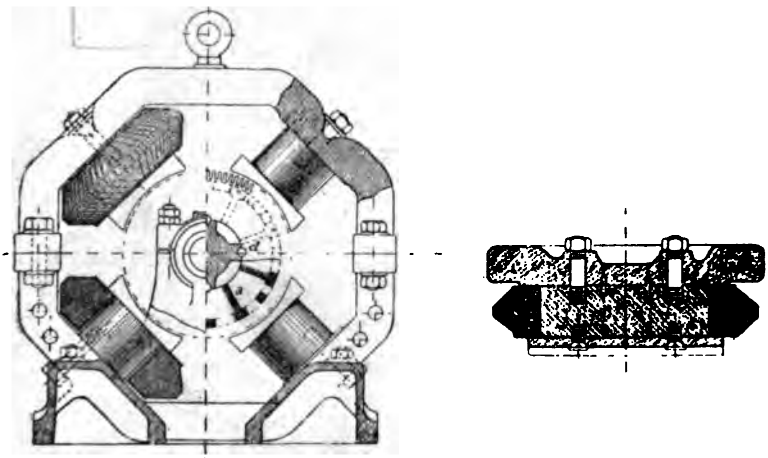


FIG. 263 *b* and *c*.—Easton-Anderson 50 kw. Dynamo at 750 revs. per min.

Besides these dynamos, which we might consider to belong to normal types, this firm constructs "homo-polar" machines, which are chiefly employed as motors, or as exciters for alternators. We have already considered a machine of this type when describing the Thury dynamos. The characteristic point about the machines at present under discussion consists in the employment of two armatures, as shown in Figs. 264 to 266. The winding does not otherwise differ from that of ordinary machines.

It has generally been considered that this type of dynamo is heavier than those with alternate poles; but experience has shown that when proper dimensions are given to the various parts of the machine, it can compare favourably with ordinary types. Further, there is no doubt that this type of machine

is well adapted for arc lighting installations, provided th: a winding has been employed which permits of sparkle: commutation beneath the poles.

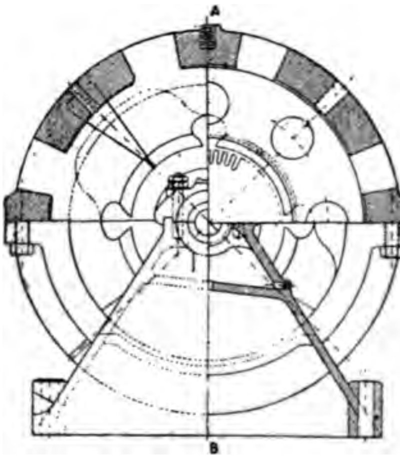


FIG. 264*a*.

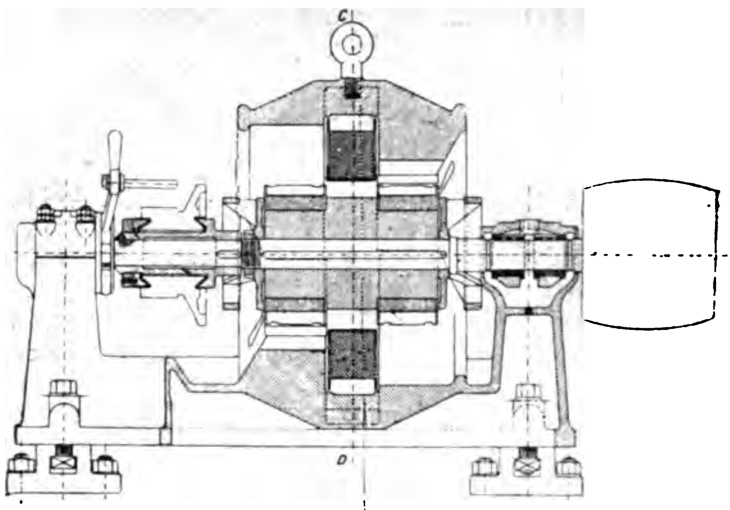


FIG. 264*b*.

As may be seen from the figures, the arc of the poles whic may be used for the displacement of the brushes is ver large, without any great magnetic leakage resulting.

The type of dynamo represented by Figs. 264 to 266 works at a pressure of 715 volts, generating 35 amperes, and having a speed of 1,300.

Number of wires in armature = $97 \times 4 = 388$.
Number of commutator sections = 97.
Diameter of armature = 30·4 cm.
Length of armature = 13·5 cm.
Air-gap = 0·2 cm.

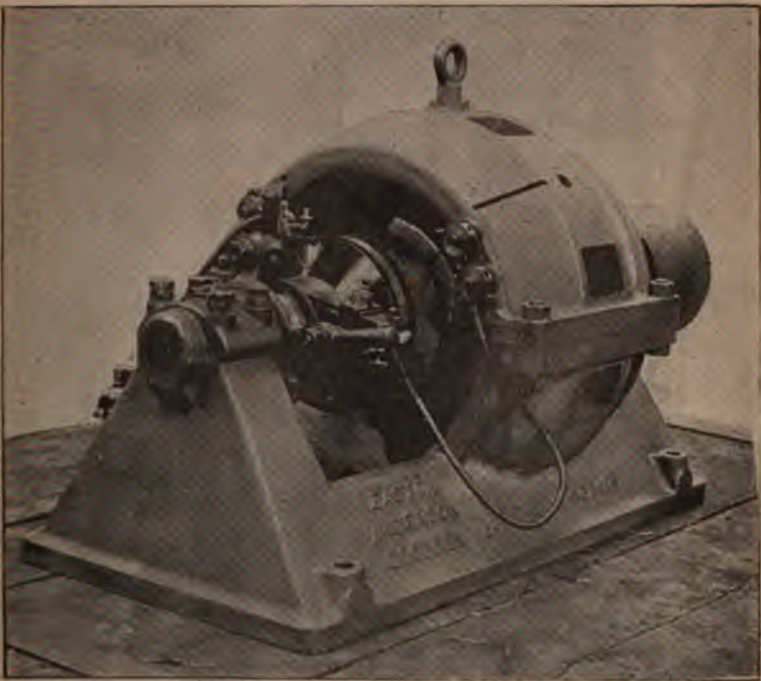


FIG. 265.

It goes without saying that the lead of the brushes will be small, on account of the considerable modification in the field strength in the neighbourhood of the neutral line; it only amounts to 2° when the copper brushes are employed. When carbon brushes are used, the angle of lead is practically equal to zero as long as the current strength does not exceed 35 amperes.

The excitation is exceptionally feeble (0·114 per cent.). According to information furnished by the makers, the dynamo which we are considering would possess a still greater output

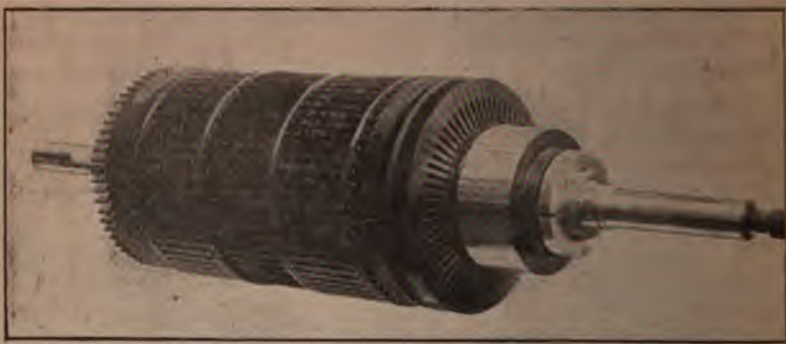


FIG. 266

if the number of commutator sections was increased. As a matter of fact, the number of commutator sections appears to be rather too small, according to the rules given on p. 299.

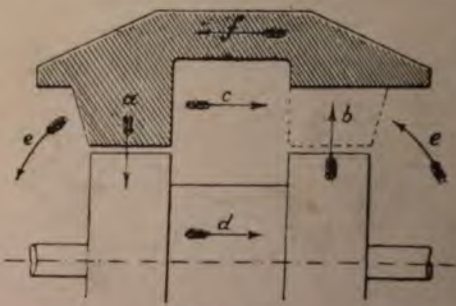


FIG. 267.

The description of a small machine of this type may be found in the *Electrician*, July 23, 1897. The armature had a diameter of 28 cm. and a length of 13 cm.

Number of commutator sections = 61.
" wires = 2 × 61 = 122.
Air-gap (single) = 0·16 cm.

The lead of the brushes was very small in this machine,

and sparkless commutation could only be obtained as the result of certain precautions. When carbon brushes were employed a great improvement resulted, and the machine could then be considerably over-loaded without producing excessive sparking.

We will give some attention to the subject of the magnetic leakage.

Let us suppose that the number of lines of force in the section f (Fig. 267) is equal to unity; these will distribute themselves in the following manner:

$$f = a + b + c + e = 1.$$
$$a = \cdot 897.$$
$$b = \cdot 0412.$$
$$c = \cdot 0418.$$
$$e = \cdot 02.$$

The leakages in e and c give rise to no further losses; on the other hand, the leakage in b will produce a real drop in potential, and therefore a diminution in output.

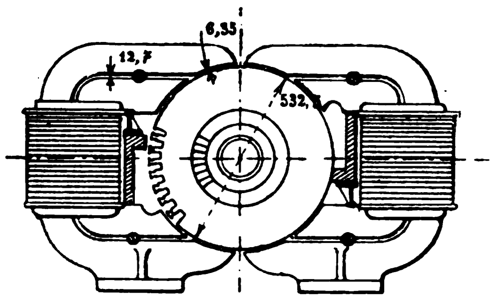


FIG. 268.

Messrs. Mavor and Coulson, of Glasgow, construct dynamos with Sayers windings, of which mention has already been made (p. 42).

We have considered that it might be useful to give some data respecting an 80-kw. machine of this type (Fig. 268), which is distinguished by its lightness.

Output: E = 100 volts.
C = 800 amperes.
n = 420 revolutions.

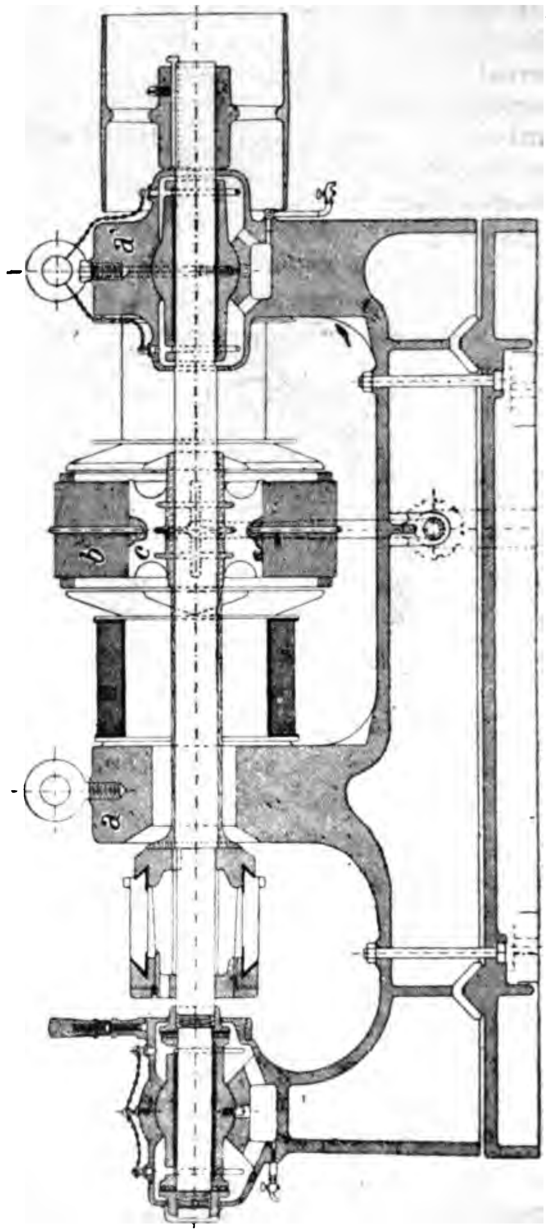


FIG. 269a.—Brush Company's Generator for Tramways.

Armature: External diameter $D = 53{\cdot}25$ cm.

Diameter of the circle passing through the bottom of the slots $= 43{\cdot}5$ cm.

Internal diameter $D_1 = 10{\cdot}8$ cm.

Length $l = 50$ cm.

Number of slots $= 72$; number of commutator sections $= 36$.

Principal winding: $N = 72$.

$s = 33{\cdot}7 \times 5$.

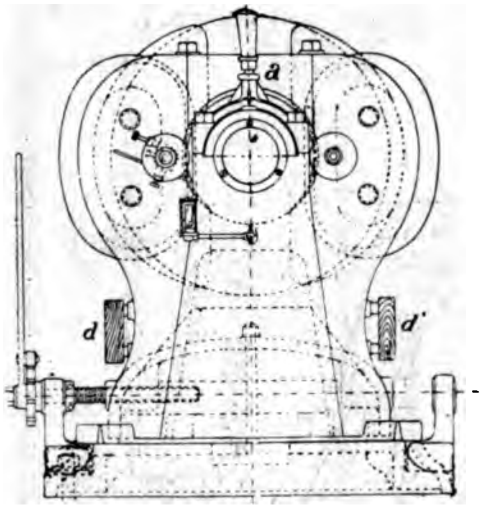


FIG. 269*b*.

Each one of the 72 notches receives one wire of the principal winding, and two wires of the compensation winding.

Field magnets:

$$\phi = \frac{(100 + 6)\ 60 \times 10^8}{72 \times 420} = 20{,}600{,}000.$$

$$S_l = 51{\cdot}6 \times 53 = 2{,}740.$$

$$B_l = \frac{20{,}600{,}000}{2{,}740} = 7{,}500.$$

The field magnets are constituted by four circuits in cast steel separated from one another by air-gaps of about $1{\cdot}3$ cm. Since the arc of the pole-pieces is 120°, and as the thickness

of a single air-gap is 0·635 cm., the strength of field due to the armature reactions (see p. 229) is

$$B'_l = \frac{4\pi}{10} 72 \times \frac{800}{2} \frac{1}{(2 \times 0·635) + (3 \times 1·3)} = 7,000;$$

whilst we have already found B_l = 7,500. But this calculation was only an approximate one, and in all probability B_l is smaller.

Number of turns per field magnet = 1,008.
Diameter of wire = 2·77 mm.
Resistance of the two coils grouped in series = 10·7 ω.

Weights.	Kgrm.
Field magnets, etc.	1,817
Parallel windings	147·4
Armature (unwound), together with shaft and commutator	1,061
Copper for armature circuit	246·6
Bearings, brush-holders, etc....	191
Total	3,463

Reproaches are often addressed to English makers on account of their prejudice for bipolar machines; on the other hand, a marked predilection for multipolar machines may be observed in the United States, four-pole machines (similar to that shown in Figs. 230 and 241) being particularly popular. An exception to this rule is supplied by the machine shown in Figs. 269 and 270, due to the *Brush Company*, of Cleveland, Ohio. The first of these machines is a generator for tramways, the second is a machine for arc lighting (see p. 248). The most characteristic features of the Brush machines are their flat ring armatures and their lateral poles. This arrangement greatly facilitates dismounting of the armature, which may be performed simply by removing the caps of the bearings, together with the relatively light piece of metal, *a*.

The core of the armature is composed of a roll of iron ribbon, which is held in position by radial bolts. The shaft is provided with projecting rings for the same purpose. The bearings are furnished with adjustable bushes, which are well adapted to this machine, although in other forms of dynamo

in which they frequently occur they might be replaced by ordinary bushes without inconvenience.

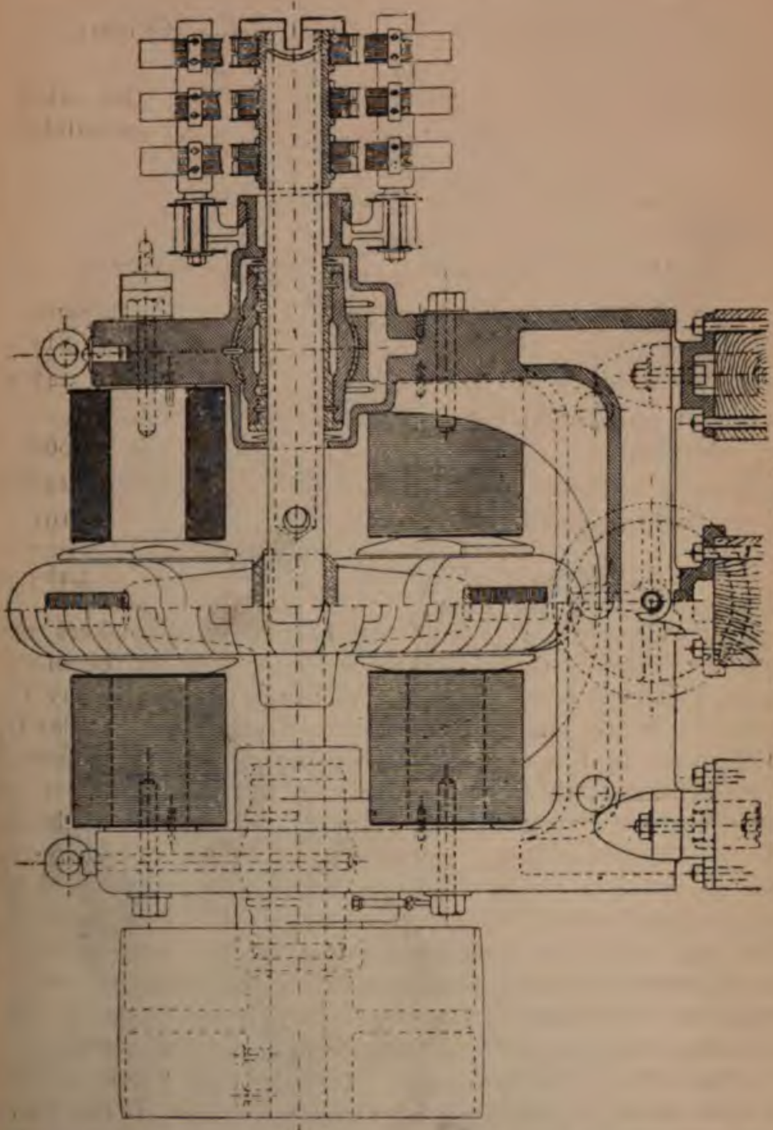


FIG. 270*a*.—Brush Company's Arc Light Dynamo.

The bend which may be admitted in an armature shaft in a dynamo with external poles is very small: so small, indeed,

that, reduced to the length of the bearing, it will scarcely exceed 0·05 mm. to 0·1 mm. It suffices, therefore, to enlarge the bushes so as to admit of this amount of play.

Another machine of American construction is shown in Fig. 271; this represents a motor which is made by the firm

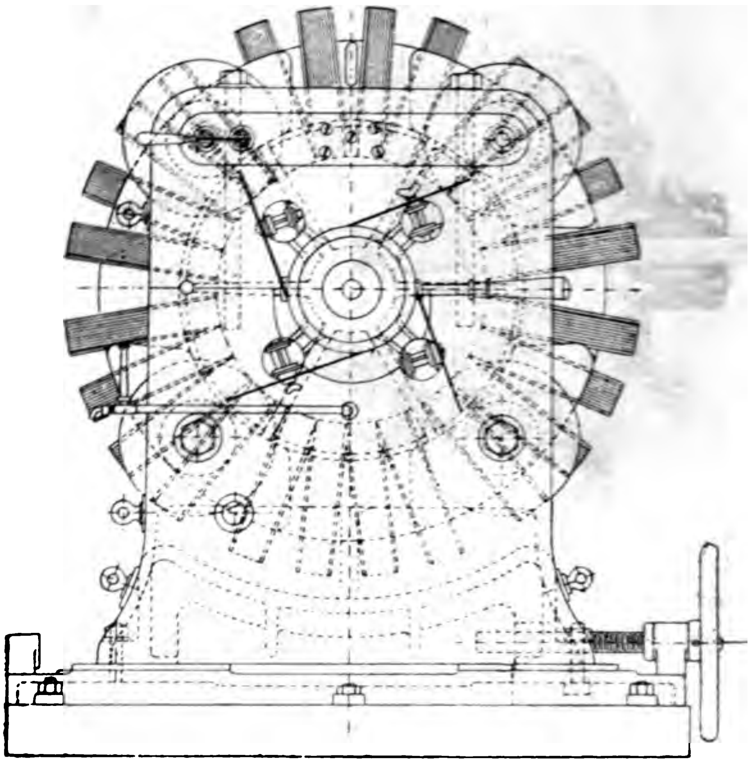


FIG. 270*b*.

best known as the constructors of *Lundell* ventilators. In this motor a curious arrangement of magnets, due to Jonas Wenström, is employed; there is a single central bobbin, and opposite poles. As a consequence, the case is in two pieces, the plane of separation being perpendicular to the axis.

This motor is furnished with roller bearings, the rollers being placed in slots cut in a bush so as to maintain them at the desired distance apart. The pressure transmitted along the axis is received on a washer of pigskin.

The *Storey Motor and Tool Company*, at Philadelphia, construct a similar motor with two field magnets, displaced along the same axis, and two central bobbins.

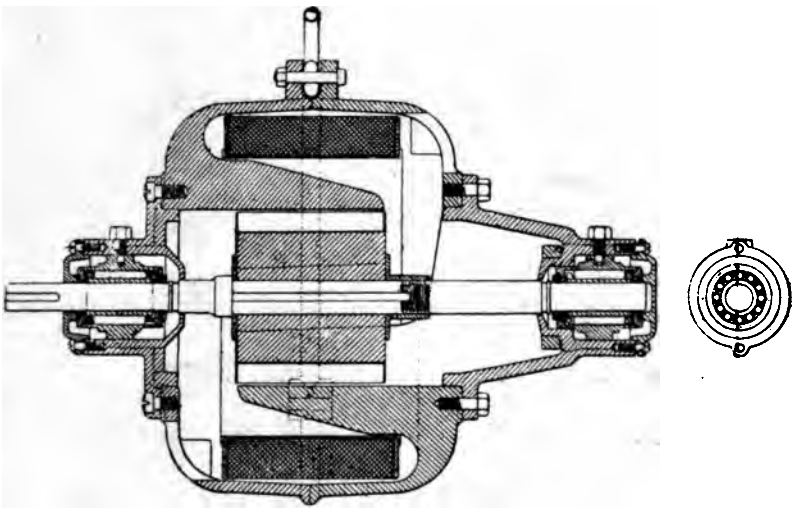


FIG. 271.

This latter arrangement presents the advantage of leading to the smallest possible value of the total weight of the machine; on the other hand, the weight of copper in the field-magnet windings is nearly doubled.

CHAPTER X.

Weight, Dimensions, and Price of Dynamos.

A. Weight.

A comparison between different dynamos can only strictly be instituted when their speeds are equal. But as the output is, between certain limits (if these are not taken too wide), proportional to the speed, we shall here compare the data referring to different machines reduced to the values they would have had if the speed had been 1,000 per minute (specific output, W_s.)

Plate III., which will be found at the end of this book, contains a certain amount of information regarding the weights of modern dynamos. It is evident that machines of the horseshoe type are relatively heavier than those of other kinds. On the other hand, the excessive weight of the Lahmeyer dynamo at once catches the eye, although this is not due to the form of the machine, since it may at once be seen that the motors for cranes made of a similar form by the Oerlikon Company weigh hardly half as much. It is true that these motors are in cast steel, and that they are not designed to work for long intervals without stopping; but the Schuckert dynamos are also much lighter than those of the Lahmeyer type. The explanation of this may doubtless be sought in the different temperatures at which the machines work. Further, the dynamos in question appear to work with a smaller number of wires and a greater field strength, which guarantees working without sparking.

Now, the question of the weight is as important for the purchaser as for the maker, since (1) the net profit depends on it; (2) heavy dynamos often possess a smaller degree of saturation, and possess disadvantages already more than once mentioned.

Care should always therefore be taken to reduce the weight of the machine as much as possible.

The curves in Plate III. show very plainly the advantages of multipolar over bipolar machines in this respect.

For this reason some firms only construct multipolar machines for this purpose, even for outputs as low as 1 kw. But, in general, *the limits for dynamos of four, six, and eight poles are as follows:*

Four-Pole Dynamos: From 6 kw. to 20 kw. (specific output);

Six-Pole Dynamos: From 100 kw. to 200 kw. (specific output);

Eight-Pole Dynamos: From 200 kw. to 300 kw. (specific output).

In preliminary calculations, especially when the machine to be constructed belongs to a series of which many have previously been made, the weight of dynamos of a given type may be taken as increasing in proportion to the two-third power of the specific output, or, in other terms,

$$\text{Weight} = c \, . \, W_s^{\frac{2}{3}}$$

(see equation 37). (c varies between 160 and 200 for dynamos with two bearings; W_s is the output for a speed of 1,000.)

When the dynamo possesses a third bearing, about 15 per cent. must be added to the total weight.

The following table gives some data respecting the weight of bearings. In this table only the upper part of the journals, together with the oil reservoir, is included; the weight of the trunk varies with the height of the bearing, and must be separately calculated.

WEIGHT OF BEARINGS.

Diameter of shaft, in millimetres	30	50	100	150	200	250	300	350	400
Length of bush, in millimetres	100	165	330	920	500	580	620	720	800
Weight, in kilogrammes	35	60	100	200	400	660	1,100	1,500	2,200

The weight of the armature is from 12 to 32 per cent. of the total weight of the dynamo. In multipolar machines, the weight of the armature will be greater relatively to the rest of the machine than in other dynamos.

For an approximate determination, supposing that the number of poles increases with the output, according to the scheme given above, we may use the following table.

WEIGHT OF ARMATURE.

Total Weight, in Kilogrammes.	Weight of Armature.	Total Weight, in Kilogrammes.	Weight of Armature.
200	12 per cent.	10,000	26 per cent.
500	16 ,,	20,000	28 ,,
1,000	19 ,,	50,000	30 ,,
2,000	22 ,,	100,000	32 ,,
6,000	25 ,,		

The relative weight of the commutator varies so much with the current, that no general rule can be formulated.

For low-tension dynamos (110 to 120 volts) the commutator weighs about 17 per cent. of the total armature weight.

Armature Spiders.

$$\text{Weight} = c\, W^{\frac{2}{3}} \text{ kgrm.} \quad . \quad . \quad . \quad (132)$$

In this formula we must substitute for c the following numbers:

For armature spider without spokes (sockets) ... ... 3 to 4.
,, ,, with thin spokes, without ribs... 8 to 10.
,, ,, with ribbed spokes ... ... 12 to 14.
For ring armatures with hub and spokes of cast iron, the rim being in bronze... ... ... 15 to 20.

In the last case, nearly half of the weight must be ascribed to the bronze rim.

Iron Discs.

$$\text{Weight (in kilogrammes)} = \frac{D^2 \pi}{4{,}000}\, l\, \gamma\, (1 - \tau^2)\, 7{\cdot}5$$

$$= 0{\cdot}006\, D^2\, l\, \gamma\, (1 - \tau^2) \text{ about} \quad . \quad . \quad . \quad (133)$$

In this formula we designate by γ the reduction of the section due to interposed paper, as well as slots, etc.

$\gamma = 0{\cdot}85$ to $0{\cdot}9$ for smooth armatures.

$\gamma = 0{\cdot}75$ to $0{\cdot}85$ for toothed armatures.

$$\tau = \frac{\text{External diameter of armature}}{\text{Internal diameter of the same}} \text{ (see p. 75).}$$

Weight of Copper.

From equation (33), we have

$$\text{Weight in kilogrammes} = 0{\cdot}45\, \frac{w}{c^2},$$

w being the loss of watts due to the resistance of the copper.
c = amperes per square millimetre.

Weight of Pulleys.

The following empirical formula is established by means of data relative to a great number of pulleys, varying in diameter from 0·1 m. to 3 m., with an internal diameter attaining as a maximum to 23 cm.

$$\text{Weight in kilogrammes} = c \, \mathrm{L} \, \mathrm{D}^2,$$

L representing the length of the pulley in centimetres;
D „ diameter „ „

TABLE OF VALUES FOR c.

D, in centimetres.	c	D, in centimetres.	c
10	0·00130	70	0·00080
15	0·00100	100	0·00076
25	0·00095	150	0·00073
50	0·00085	225	0·00070

The above formula leads to sufficiently concordant results; the greatest discrepancy between the observed and the calculated values will not generally amount to more than ± 15 per cent.

For example, a pulley of 100 cm. diameter and a length of 50 cm. weighs $0·00076 \times 56 \times 100^2 = 380$ kgrm.

Weight of Yoke.

The weight of the yoke, properly so called, taken apart from the base-plate and journals, can be determined with a certain amount of accuracy, when the length, L, of the lines of force and the section, S, are known, from the formula

Weight in kilogrammes =

$$\left(L_m S_m + L'_m S'_m + L''_m S''_m + \ldots\right) \frac{7·2}{1,000}.$$

In the case where the field magnets are made of cast steel, we may replace the coefficient 7·2 by 7·8 or 7·9.

B. Dimensions.

The following tables do not refer to special machines, but may rather be considered as giving the mean values determined from a great number of dynamos. They may therefore be of service in designing dynamos.

W_s = specific output in kilowatts.

Vertical Horseshoe Type.

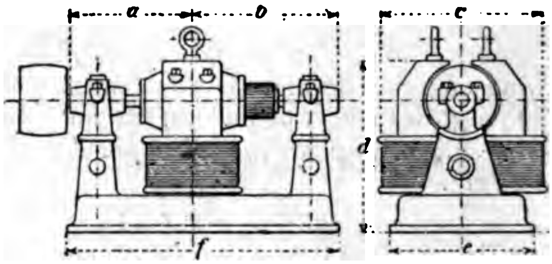


Fig. 272.

W_s	1	2	4	8	12	20	30	50	75	100	150
a	220	270	330	400	440	490	540	625	710	785	910
b	380	460	530	600	650	720	785	890	985	1,060	1,160
c	310	380	440	520	570	660	740	860	960	1,050	1,130
d	310	420	500	590	650	750	850	980	1,100	1,200	1,300
e	280	340	400	470	520	600	680	790	885	960	1,050
f	630	720	850	980	1 060	1,190	1,300	1,480	1,650	1,790	2,000
h	280	340	400	470	520	600	680	790	885	960	1,050

Manchester Type.

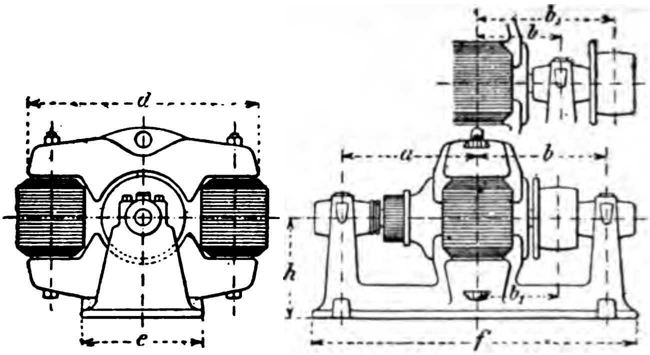


Fig 273.

W_s	1	2	4	8	12	20	30	50	75	100	150
a	230	290	340	410	470	550	620	700	735	750	780
b	230	290	340	410	470	550	620	— (700)*	— (735)	—	
b_1	150	180	225	280	320	380	430	720 (500)	790 (550)	840	910
d	500	600	680	770	820	950	1,050	1,200	1,360	1,485	1,670
e	180	210	250	310	350	410	465	555	650	730	850
f	550	720	870	1,060	1,180	1,340	1,480	1,290 (1,690)	1,460 (1,860)	1,580	1,800
h	150	180	225	280	320	380	430	500	550	580	630

Overhanging pulley.

* *The numbers between parentheses are applicable to the case where the pulley is not overhanging, but is situated between two bearings.*

BIPOLAR VERTICAL TYPE.

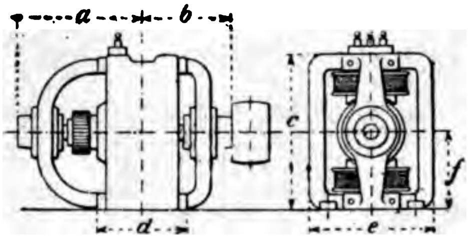


FIG. 274.

W_s	0·4	0·7	1	1·5	3	5	8	12	15	18
a	260	290	310	335	390	445	510	585	635	680
b	176	200	210	230	276	320	365	415	450	475
c	395	420	445	475	535	576	640	690	720	745
d	—	—	—	—	—	—	—	—	—	—
e	245	275	290	320	380	430	495	550	575	600
f	$f = \frac{c}{2}$ + a small quantity.									

MULTIPOLAR MACHINES (FOUR-POLE).

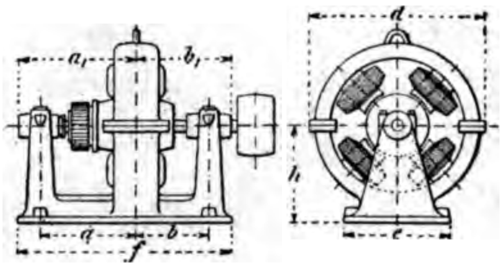


FIG. 275.

W_s	10	20	30	50	75	100	130	160	200
a	460	470	490	530	580	610	700	730	790
a_1	575	600	620	670	725	780	860	930	970
b	314	330	340	370	400	430	470	490	510
b_1	450	470	485	515	555	600	650	675	700
c	570	600	630	670	720	780	860	930	970
d	830	865	900	975	1,065	1,150	1,210	1,260	1,340
e	505	530	550	595	650	700	790	870	970
f	1,020	1,070	1,120	1,225	1,350	1,480	1,510	1,540	1,590

MULTIPOLAR DYNAMOS (TYPES WITH SIX, EIGHT, OR MORE POLES).

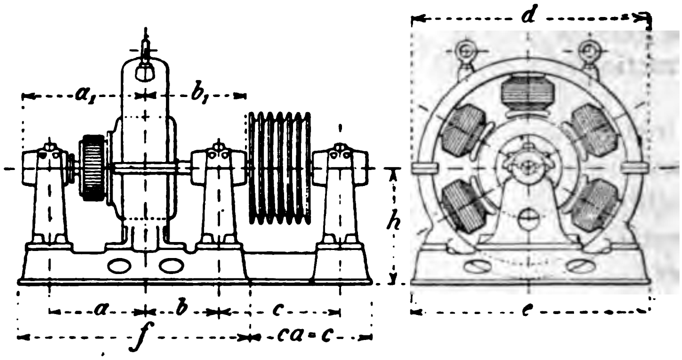


FIG. 276.

W_s	300	500	750	1,000	1 500	2,000	2,700
a	830	860	900	970	1,000	1,040	1,100
a_1	1,030	1,090	1,125	1,170	1,220	1,270	1,330
b	510	560	615	665	710	750	790
b_1	740	780	845	900	950	1,000	1,050
c	1,000	1,100	1,150	1,200	1,300	1,400	1,500
d	1,500	1,850	2,250	2,600	3,100	3,400	3,600
e	1,300	1,600	2,000	2,400	2,900	3,200	3,400
f	1,700	1,890	2,120	2,300	2,580	2,770	2,960
h	1,540	1,700	2,000	2,140	2,400	2,600	2,800

C. Calculation of Cost of Construction.

The following figures must naturally be considered as subject to variation between wide limits, according to the situation of the workshops and the prices of labour and of materials. In regard to the expenditure on salaries and wages, it is assumed that several machines are at all times simultaneously in course of construction. When the cost of construction of a single machine, made by itself, is required. we must multiply the prices given by a suitable factor, greater than 1. Moreover, the cost of patterns for the cast-iron parts has not been included in the grand total.

The cost of construction comprises:

1. The cost of raw materials, to which must be added rent, waste, and cost of carriage.
2. Wages for manual labour.

3. General expenses, expressed generally as a percentage of the wages for manual labour.

The relative weights of different substances used in the construction of a dynamo are roughly as follows:

Cast iron or cast steel ...	70 to 80	per cent. of total weight.
Wrought iron	3 to 5	,, ,, ,,
Wrought-iron discs	8 to 12	,, ,, ,,
Gunmetal	2 to 5	,, ,, ,,
Copper...	8 to 11	,, ,, ,,

The cost of materials is considered in the following table (p. 398). The third column refers to the weight lost in machining the various parts, and might be considered worthless, copper wires not excepted. The length of these latter should always be taken 2 or 3 per cent. in excess of that actually required, whilst the waste cannot generally be used for other purposes.

We should add about 15 to 20 per cent. to the above values for rent, breakages, and ordinary waste.

The total cost of manual labour (in Switzerland) could be estimated in the following manner, assuming average wages:

Kilogrammes	250	500	1,000	2,000	4,000	6,000	10,000
Cost, in pence, per kilogramme...	$4\frac{1}{2}$	4	$3\frac{1}{4}$	$2\frac{1}{2}$	$1\frac{3}{4}$	$1\frac{1}{2}$	$1\frac{1}{4}$

It would be useless to give details of these prices, since the cost of certain different operations may vary more than the total price given. It would, however, be interesting to know the price of winding, which attains to from 20 to 30 per cent. of the total price of the dynamo.

The general expenses will depend entirely on the organisation of the workshop, and the importance of the annual establishment charges. The more perfect the plant is, the more important will become the establishment charges; on the other hand, the cost for manual labour will diminish. Whilst it used to suffice, in certain cases, to add 100 per cent. to the cost of manual labour, in modern workshops from 150 to 180 per cent.

APPROXIMATE COST PRICE OF RAW MATERIALS USED IN DYNAMO CONSTRUCTION.

Materials.	Specific Gravity.	Loss in Machinery.	Approximate Cost Price.
1. IRON.		Per cent.	
Grey cast iron	7 2	5 to 7	9s 6d. to 13s. 6d. per cwt.
Steel castings	7 8 to 7 9	6 to 8	Up to 2 cwt. 20s. to 28s. per cwt. Over 2 cwt., 18s. 6d. to 22s. per cwt.
Bar iron	7 6 to 7 8	6	7s to 9s per cwt.
Steel for shafts	,	6	12s 6d. to 16s. 6d per cwt.
Sheet iron for armatures	,,	15	10s. 6d. to 13s. 6d. per cwt.
Iron ribbon for disc armatures	,,	5	About £1 per ton.
2. GUNMETAL CASTINGS ...	8 3 to 8·8	10	8½d to 10½d. per lb.
3. ZINC, in plates	7 0	10	7½d per lb.
4. COPPER.			
Drawn wires and bars ...	8 8 to 9·0	2 to 3	7½d to 9½d. per lb.
Stranded copper	,,	2 to 3	8 or 10 per cent more than solid copper wires or bars of the same section.
Sheet copper	,,	—	£66 per ton.
Commutator segments ...	,,	—	10½d to 1s. 2d. per lb.
Steel binding wires	—	—	9d. to 1s. per lb.
5. MICA, in crystals 1½in. by 8in.	2·8	10 to 20	3s 6d. to 4s. 6d. per lb.
In larger crystals	,,	10 to 20	4s. 6d. to 25s. per lb.
Sheet micanite	—	—	3s. 9d. to 6s. per lb.
6. EBONITE	1 3	—	6s. 3d. per lb. These prices vary with the quality of ebonite used.
Shaped pieces...............	,,	—	4s. 2d to 6s. 3d. per lb.
Tubes, unpolished.........	,,	—	5s 10d. per lb.
7. AMIANTHUS	2·1 to 2·8	—	—
In sheets...........	,,	—	About 3s. 4d. per lb.
In bobbins	,,	—	
Vulcasbeston, in sheets / ,, tubes	,,	—	3s. 4d. to 4s. 2d. per lb.
8. FIBRE, in sheets	,,	—	2s. 3d. per lb.
9. PAPER.			
For insulation of armature discs....................	,,	—	2d. to 3½d per lb.
Presspahn	1·28	—	6d. to 7½d. per lb.
Bobbins shaped from Presspahn	—	—	3s 5d. to 5s. For the former, 4s. 2d. to 8s. 4d.

CHAPTER XI.

RECAPITULATION OF FORMULÆ TO BE USED IN THE DESIGN OF DYNAMOS.

The difficulty in designing a machine does not greatly depend on the calculations properly so called, but more in determining in what manner the existing formulæ should be applied. Before commencing, it is necessary, though difficult, to choose from the mass of formulæ at our disposal those which will lead most quickly to the desired end.

To facilitate this choice, we will give in this chapter a rapid recapitulation of the most important of the formulæ determined in the preceding pages in the order in which they will be needed.

We are generally given—

The output, depending on E and C;
The speed, n;
The commercial efficiency, ζ.

Moreover, a series or shunt winding is generally prescribed.

The remaining data for the construction of the machine must be determined.

When a generator is being designed, we can, if the number of poles is not already prescribed, make use of the following rule:

Four-pole dynamos should be constructed when the specific output (as previously defined) is greater than 6 kw. to 20 kw.

Six-pole dynamos should be constructed when the specific output is greater than 100 kw. to 150 kw.

Eight-pole dynamos should be constructed when the specific output is greater than 200 kw. to 300 kw.

The loss calculated on the base of the prescribed commercial efficiency should be distributed into the separate constituents,

$$w_a,\ w_h,\ w_r,\ w_m,\ \text{etc.}$$

a_m should not be smaller than a certain value, since, in the contrary case, the dynamo would be too sensitive to variations in the current strength and speed.

The calculations may be divided into:

A. Those relating to the armature.
B. " " field magnets.

For the choice of the type of dynamo to be used we may consult Plate II.

The numbers in parentheses refer in every instance to the equations in this book.

A. Armatures.

D = diameter in centimetres.
l = length " "
$\lambda = \dfrac{l}{D}$.

1. First Approximation to Exterior Dimensions.

$$D = 39\sqrt{\frac{EC}{n} \cdot \frac{1}{l}} = 11{\cdot}5\sqrt[3]{\frac{EC}{n} \cdot \frac{1}{\lambda}} \quad (50) \text{ and } (52)$$

for ring windings.

$$D = 32\sqrt{\frac{EC}{n} \cdot \frac{1}{l}} = 10\sqrt[3]{\frac{EC}{n} \cdot \frac{1}{\lambda}} \quad . \quad . \quad (51) \text{ and } (53)$$

for drum windings (see pp. 69 and 70).

The formulæ for drum-wound armatures apply to generators and give very good results for machines whose outputs are between 15 kw. and 400 kw.: for smaller machines a value of **D** slightly greater than that obtained by the formula must be taken: for more powerful machines a lower value must be used. In the case of motors, we must take E C = 746 h.p. We may equally well consult the table of values obtained from machines actually made (pp. 78 and 79).

Verification.—The peripheral speed of the armature should not exceed 25 m. to 30 m.

Dimensions of Wire.

Approximate section of wire =

$$s = \frac{C}{p_1 \cdot 180\, e} \text{ square millimetres.} \quad . \quad . \quad (56)$$

ϵE = resistance loss (0·02 E to 0·06 E).

Thickness of insulation (pp. 65 to 68).

Referring to Fig. 47, and supposing that N′ is the number of turns for a length of u_1, the total number of wires will be

$$N = \frac{D \pi}{u_1} N' ;$$

and we must have

$$N < 6{\cdot}37 \frac{B_l \delta p_1 p}{C \beta}.$$

B_l being the density of lines of force in the air-gap.

δ = the air-gap in centimetres, and for β (see Fig. 126).

In a similar manner the pole-pieces may also be designed.

We obtain B_l from equation (10):

$$B_l = \frac{E' \, 60 \times 10^8 p_1}{n \, N \, p} \, \frac{1}{b \, l} ;$$

in which

b is the arc of a pole-piece, in centimetres $= \frac{D \pi}{2 p} \beta$.

E' = the E.M.F. $= (1 + \epsilon') E$.

ϵ' = the drop in voltage = 2ϵ to 3ϵ (about), when account is taken of the armature reactions.

2. Second Approximation.

$$D = \sqrt{\frac{E' p_1 u_1 12 \times 10^8}{n N'' \beta B l}} . \quad . \quad . \quad . \qquad (57)$$

(See p. 72.)

Verification.—Determination of L, the exact length of the winding:

$$\text{Diameter of wire } S = \frac{L N C}{200 \epsilon E p_1^2} \text{ sq. mm.} \quad . \quad (29)$$

We must determine whether this winding could be executed.

Rules for executing a winding (pp. 20 to 35).

Comparison of drum with ring windings (pp. 35 to 38).

As the maximum number of commutator sections is equal to $N_2 = \frac{N}{2}$ for drum windings, and to N in the case of ring windings, we must assure ourselves, particularly in the case

of a high-voltage dynamo, that the maximum pressure between two commutator sections

$$e_2 = \frac{E\,2\,p}{N_2}$$

is not greater than 30 or 40 volts. Eventually, we may modify the winding or the number of poles.

The saturation in the slots of the armature should not exceed 16,000 to 17,000.

3. Determination of the Interior Diameter of the Armature.

(See pp. 75 to 77.)

$$\phi = \frac{E' 60 \times 10^8 p_1}{n N p} \quad . \quad . \quad . \quad . \quad . \quad . \qquad (10)$$

$$B_a = \frac{\phi}{S_a}.$$

We have approximately

B_a = 14,000 to 16,000 in the case of two-pole dynamos.
= 12,000 to 14,000 ,, four ,,
= 9,000 to 12,000 ,, six ,,

On the other hand, dynamos actually made give approximately the following values for $\tau_1 = \frac{D_1}{D}$:

Number of Poles.	τ_1.
2	0·3 to 0·4
4	0·6 to 0·65
6	0·65 to 0·70
8	0·70 to 0·80
10	0·78 to 0·83
12	0·80 to 0·85
14	0·9

Calculation for Verification.

Loss of watts due to hysteresis

$$w_h = \eta\, B_a^{1.6}\, \omega\, V\, 10^{-7} \quad . \quad . \quad . \quad . \quad . \quad . \qquad (34)$$

$$\omega = \frac{p\,n}{60}.$$

V = volume of iron in cubic centimetres.

In making a more exact calculation, we may determine also the hysteresis losses in the slots, and subtract that from the loss in the following calculation:

Suppose that

D_1 = the interior diameter;

D = diameter of circle passing through crests of teeth;

D' = the diameter of the circle passing through the bottom of the slots ($D' = D$ in the case of smooth armatures); then

$$\tau D' = D_1.$$

We may find most rapidly by the aid of Table VIII. (p. 414)

$$\frac{(1-\tau)^{0\cdot 6}}{1+\tau} = \frac{2\cdot 5}{10^{10}} \frac{\phi^{1\cdot 6}}{D'^{0\cdot 2}} \frac{1}{\lambda^{0\cdot 6}} \frac{\omega}{W_h} = A.$$

Table VIII. gives the value of τ for any value of A. We have approximately $\tau = 1 - \mathbf{A}$.

4. Calculation of the Heating.

Rise in temperature, in degrees Centigrade =

$$\frac{225 \times (W_a + W_h)}{\text{Surface (in sq. cms.)}} \quad . \quad . \quad . \quad . \quad (58)$$

According to another formula, we have—

Rise in temperature, in degrees Centigrade =

$$\frac{645\,(W_a + W_h)}{\text{Surface } (1 + 0\cdot 3\,\sqrt{v})},$$

v representing the peripheral speed, in metres.

5. Dimensions of the Commutator.

These dimensions should be as small as possible.

For metallic brushes we have—

Surface for rubbing contact (in square millimetres per ampere) =

$$5 + \frac{\text{about } 200}{\text{Amperes per line of brushes}} \quad . \quad . \quad (129)$$

In the case of carbon brushes we will take as a minimum 13 to 15 square millimetres per ampere.

6. Determination of Lead of Brushes.

$$\frac{r\,T}{L} = 2\,\frac{D\,\beta\,B_l\,p_1\,\gamma\,\epsilon}{D_1\,C\,u'\,(1 \pm \epsilon')\,q} \quad . \quad . \quad . \quad (104)$$

In this formula, we designate by

γ (see Fig. 126), the arc of contact of a brush, in centimetres.

D_1, the diameter of the commutator, in centimetres.

u', a coefficient which is equal to

2·3 in toothed armatures;

3 in armatures with half-closed slots:

4 to 5 in tunnelled armatures;

0·4 in smooth armatures;

q, the number of wires per slot; in the case of smooth armatures, $q = \frac{N}{N_2}$.

In generators we must take $(1 + \epsilon')$, in motors $(1 - \epsilon')$.

The corresponding value of η will be given in Table XI., and we may hence calculate the lead of the brushes

$$a = \sqrt{M^2 + \left(c + \frac{\delta}{\xi}\right)^2} - M \quad . \quad . \quad . \quad (106)$$

(for c, δ, and ξ, see Fig. 126).

In this equation

$$M = \frac{\delta\,(1 \pm \epsilon')}{\xi\,\beta\,\epsilon\,\eta} \quad . \quad . \quad . \quad . \quad . \quad . \quad (107)$$

For well-made dynamos we shall have $\frac{a}{c} < 0·6$; if the quotient is greater than 0·7, the dynamo may be useless, or at best will work very badly.

In the case of motors the angle of lead is smaller than that calculated from the above formula; the same thing applies to machines with carbon brushes.

7. Diameter of Shaft.

Let us denote by

d, the diameter of the smallest section in centimetres (this will be found between the commutator and the armature);

n, the speed;

W, the commercial output in kilowatts;

H.P., the commercial output in horse-power.

Shaft in Forged Iron.

$$d = 20\sqrt[3]{\frac{\text{H.P.}}{n}} = 23\sqrt[3]{\frac{W}{n}} \quad . \quad . \quad . \quad (114)$$

Shaft in Steel.

$$d = 18\sqrt[3]{\frac{\text{H.P.}}{n}} = 21\sqrt[3]{\frac{W}{n}} \quad . \quad . \quad . \quad (115)$$

This formula gives, for dynamos of less than 100 h.p., a diameter slightly too large, and for dynamos below 15 h.p. a diameter too small. Compare with table referring to shafts actually made. Table for keys, XI., p. 416.

B. Field Magnets.

It is now assumed that the armature has been designed in such a manner as to satisfy the conditions imposed at the outset, and that we have satisfied ourselves, by means of a brief and approximate calculation, that the dimensions of the dynamo are well proportioned. It may be remarked, in passing, that this calculation to verify the dimensions chosen should never be omitted. It now remains to determine the dimensions and winding of the field magnets.

We will roughly design the field magnets, reserving an approximate space for the winding. As, in general, dynamos require from two to four times (or on an average $2\frac{1}{2}$ times) as many ampere-turns as are required in the armature, we will suppose, as a first approximation, $C_m \, N_m$ for the magnetic circuit $= \frac{C\,N}{4\,p\,p_1}\,2{\cdot}5$, where $\frac{C\,N}{2\,p_1}$ represents the ampere-turns round the armature.

The approximate space for winding will then be given (see p. 321):

$$= c\,\frac{(\text{Ampere-turns per bobbin})^2}{50\,w}\,L \quad . \quad . \quad (131)$$

L being the mean length of the winding, in metres ;
w, the loss in watts per bobbin.

We must substitute for c a value obtained from the following table:

Diameter of wire, d, in mm.	0·5	1	2	3	4	5 and over.
Rectangular winding $c =$	5	2·9	2·15	1·86	1·68	1·57
Conical winding $c =$	3·75	2·2	1·6	1·4	1·26	1·18

When, in this manner, we have determined approximately the probable length of the lines of force, we can proceed to make a more exact calculation of $C_m N_m$, making use of the method employed in obtaining equation (76), p. 154.

Part of Magnetic Circuit.	Section S in sq. cm.	Leakage Coefficient ν or κ.	Density of Lines of Force, B per sq. cm.	Length of Lines of Force, L, in cm.	Ampere-turns per cm. Length, f(B).	Total Ampere-turns, $C_m N_m$.
Pole-pieces						
Yoke						
Armature						
Air-gap						
		Total...	... ...	... ...		

For ν, see Table X. (p. 415); for κ, p. 161; for f(B), Plate I.

This table suggests the following observations:

1. In the case of series-wound dynamos we may determine ϕ from the E.M.F.—that is to say, from the brush voltage + the drop in voltage (– in the case of motors): it is the same for shunt-wound dynamos.

2. In the case of compound-wound dynamos we must make two calculations; we take the flux ϕ, calculated from the brush voltage, for the base of the first (this gives the shunt winding), and for base of the second we take ϕ calculated from the E.M.F. The difference of the two values will give the ampere-turns of the compound winding (see p. 197).

$$\text{Section of wire } s = \frac{(C_m N_m)\, N_1 L}{E\ 50} \text{ square millimetres,}$$

N_1 being the number of coils mounted in series, $C_m N_m$ the ampere-turns of one coil, and E the pressure at the extremities of the field-magnet windings. In series or compound wound dynamos E is equal to the total drop in voltage (ϵ E); in a shunt-wound machine it is equal to the brush voltage.

To effect the necessary regulation, the wire should be rather thicker in a shunt-wound machine.

Number of Turns per Bobbin.

$$\mathbf{N}_m = \frac{\mathbf{C}_m \mathbf{N}_m}{\mathbf{C}_m} = \frac{\mathbf{C}_m \mathbf{N}_m}{\epsilon \mathbf{C}} \quad . \quad . \quad . \quad . \quad (64)$$

Verification.—We should assure ourselves that the windings can be performed in the space provided, and when needed, the calculations must be repeated.

Heating of Field Magnets.

Rise in temperature, in degrees Centigrade,

$$= \frac{335 \times \text{Loss in watts per bobbin}}{\text{Surface of a bobbin in sq. cm.}}$$

When the dynamo has been calculated out in the manner indicated, it is necessary to make a summary of the figures, so as to be able to judge at a glance of their relative fitness as well as to make it possible for a second person to verify them at any time. The following practical hints may not be useless in this connection:

If the dynamo is definitely determined, the given electrical conditions, and those which are indispensable in the construction, should be written on a detached leaf—similar to that given at the end of this book; they should afterwards be preserved and classified. The back should be reserved for experimental results. It is of course unnecessary to repeat results obtained with machines identical in construction. On the other hand, when any variation is effected, whether in the dimensions or the winding, or even in castings, the weights can equally well be suppressed when the new machine is of a known type.

As far as concerns the trials, the following should be noted:

1. The characteristic curve, when the machine is working on open circuit, taken in connection with the excitation and the voltage.

2. A certain number of voltage curves obtained with a constant exciting current, and a variable strength of the armature current.

3. A measurement of the armature and field-magnet resistances.

4. The insulation between the windings and the base-plate.

5. The increase in temperature of the machine after several hours' working; whenever this is possible, the increase in temperature should be calculated from the resistance of the windings.

6. Observations concerning the formation of sparks and the displacement of the brushes should be noted.

CHAPTER XII.

TABLES.

I.—TABLE OF SPECIFIC RESISTANCES.*

ρ_0 = specific resistance at 0° C.
σ = temperature coefficient per 1° C.

Substances.	ρ_0	σ.	Observations.
Aluminium	0·03 to 0·05	0·0039	—
Aluminium bronze	0·12	0·001	—
Antimony	0·5	0·0041	—
Bismuth	1·2	0·0037	—
Brass	0·07 to 0·08	0·0015	—
Carbon	100 to 1,000	0·0003 to 0·0008	—
Carbon (retort)	40 to 120	40 to 120	—
Constantan (Basse and Selve, Altona)	0·5	0·00003	58 Cu, 41 Ni, 1 Mn.
Copper	0·0161 to 0·018	0·0037 to 0·0039	Lazare, Weiller, and Co., Paris.
German silver	0·15 to 0·36	0·0003 to 0·0004	—
Iron	0·1 to 0·12	0·0045	—
Kruppine (F. Krupp, Essen)	0·85	0·0008	—
Lead	0·22	0·0041	—
Magnesium	0·04	0·0039	—
Mercury	0·95	0·00091	—
Nickel	0·15	0·0057	—
Nickeline (Fleitmann, Witte & Co., Schwerta	0·44	0·0002 to 0·00008	55 Cu, 25 Ni, 19·5 Zn.
Phosphor bronze	0·10	—	—
Platinum	0·12 to 0·16	0·0024 to 0·0035	—
Silver	0·016 to 0·018	0·0034 to 0·004	—
Steel	0·10 to 0·25	0·0052	—
Tin	0·10	0·0042	—
Zinc	0·06	0·0042	—

$$R = \frac{L}{s}\,\rho \quad (15). \qquad \rho = \rho_0\,(1 + \sigma\,t) \quad (16).$$

* Taken from "Hülfsbuch für Elektrotechnik" by Grawinkel and Strecker, fourth edition, Berlin, 1895.

II.—Wire Table.

Diameter.	Section.	Weight of 1 km.	Resistance of 100 m.	Diameter.	Section.	Weight of 1 km.	Resistance of 100 m.
mm.	mm².	kgrm.	ohms.	mm.	mm².	kgrm.	ohms.
0·1	0·008	0·069	212·892	3·60	10·18	90·5	0·16450
0·2	0·031	0·279	53·298	3·70	10·75	95·6	0·15604
0·3	0·071	0·629	23·688	3·80	11·34	100·8	0·14758
0·4	0·126	1·118	13·348	3·90	11·95	106·2	0·14006
0·5	0·196	1·745	7·545	4·00	12·57	111·8	0·13348
0·6	0·283	2·52	5·922	4·10	13·20	117·8	0·12690
0·7	0·385	3·41	4·352	4·20	13·85	123·4	0·12032
0·8	0·503	4·47	3·328	4·30	14·52	129·2	0·11468
0·9	0·636	5·67	2·632	4·40	15·20	135·6	0·10998
1·00	0·785	6·98	2·128	4·50	15·90	141·3	0·10528
1·05	0·860	7·69	1·922	4·60	16·62	148·1	0·10058
1·10	0·950	8·42	1·765	4·70	17·35	154·1	0·09682
1·15	1·041	9·20	1·607	4·80	18·10	161·0	0·09212
1·20	1·131	10·02	1·48	4·90	18·86	168·0	0·08836
1·25	1·229	10·88	1·36	5·0	19·64	174·5	0·07545
1·30	1·327	11·79	1·28	5·5	23·76	212	0·07050
1·35	1·431	12·70	1·166	6·0	28·27	252	0·05922
1·40	1·539	13·64	1·081	6·5	33·18	294	0·05038
1·45	1·631	14·62	1·017	7·0	38·14	341	0·04352
1·50	1·767	15·67	0·949	7·5	44·18	392	0·03788
1·55	1·887	16·80	0·884	8·0	50·27	447	0·03328
1·60	2·001	17·90	0·8272	8·5	56·74	505	0·02952
1·65	2·138	19·05	0·7802	9·0	63·62	567	0·02632
1·70	2·270	20·20	0·7332	9·5	70·88	629	0·02359
1·75	2·405	21·43	0·6956	10·0	78·55	698	0·02124
1·80	2·544	22·65	0·6580	10·4	85	756	0·0196
1·85	2·688	23·86	0·6204	10·7	90	801	0·0185
1·90	2·835	25·24	0·5922	11·0	95	845·5	0·0176
1·95	2·982	26·85	0·5612	11·3	100	890	0·0166
2·00	3·142	27·90	0·53298	11·8	110	979	0·0152
2·10	3·464	30·80	0·4794	12·35	120	1,068	0·0139
2·20	3·976	33·90	0·4418	12·87	130	1,137	0·0128
2·30	4·155	36·90	0·4042	13·35	140	1,246	0·0119
2·40	4·524	40·30	0·3666	13·81	150	1,335	0·0111
2·50	4·909	43·60	0·34028	14·27	160	1,424	0·0104
2·60	5·309	47·30	0·3196	14·7	170	1,513	0·0098
2·70	5·726	51·00	0·2914	15·15	180	1,602	0·00927
2·80	6·158	54·80	0·2726	15·5	190	1,691	0·0088
2·90	6·605	58·9	0·2538	15·95	200	1,780	0·00835
3·00	7·069	62·9	0·23688	16·7	220	1,958	0·00760
3·10	7·548	67·1	0·22090	17·5	240	2,136	0·00695
3·20	8·043	71·6	0·20774	18·2	260	2,314	0·00641
3·30	8·553	76·1	0·19552	18·9	280	2,492	0·00596
3·40	9·08	80·8	0·18424	19·5	300	2,670	0·00556
3·50	9·62	85·8	0·17390				

III.—Table of Cables (Lazare, Weiller, and Co.).

Number of Wires.	Diameter of each Wire. mm.	Diameter of Cable. mm.	Solid Wire Equivalent Diameter. mm.	Solid Wire Equivalent Sectional Area. mm².	Weight of a Kilometre. kgrm.	Resistance of a Kilometre at 15·5° C, ohms.
3	0·508	1·07	0·86	0·585	6	29·07
3	0·609	1·29	1·06	0·893	8	20·10
3	0·711	1·50	1·24	1·216	11	14·83
7	0·508	1·54	1·36	1·423	13	12·43
7	0·609	1·83	1·62	2·075	19	8·63
7	0·711	2·13	1·90	2·849	25	6·337
7	0·762	2·28	2·03	3·242	29	5·525
7	0·838	2·51	2·23	3·923	35	4·561
7	0·914	2 74	2·43	4·65	42	3 835
7	1·02	3·04	2·71	5·77	52	3·108
7	1·22	3·66	3·25	8·30	74	2 158
7	1·42	4·27	3 78	11·28	100	1·585
7	1 63	4·88	4·34	14·73	132	1·213
7	1·83	5·49	4·87	18·66	166	0·959
7	2·03	6·10	5·41	22·98	205	0·778
19	0·914	4·57	4·03	12·74	113	1·404
19	1·02	5·08	4·47	15 72	140	1·137
19	1·22	6 10	5·35	22·66	201	0·7897
19	1·42	7·10	6·27	30·91	274	0·6704
19	1·63	8·12	7·16	40·25	358	0·4445
19	1·83	9·14	8·05	50·96	453	0·3512
19	2·03	10·1	8·94	62·77	559	0·2845
19	2·34	11·6	10·7	83·20	740	0·2151
19	2·64	13·2	11·6	106·30	945	0·1683
37	1·63	11·3	10·0	78·6	699	0·2274
37	1·83	12·8	11·2	99·6	885	0·1797
37	2·03	14 2	12·5	122·7	1,093	0·1456
37	2·34	16·3	14·3	162·7	1,445	0·1101
37	2·64	18·4	16·2	207·7	1,847	0·0861
61	2·34	21·0	18·5	268·7	2,389	0·0666
61	2 64	23·7	20·9	343·4	3,052	0·0521

IV.—HYSTERESIS COEFFICIENTS (η).

(After MR. CH. P. STEINMETZ (see p. 49.)

Metal.	η
Soft iron wire (Ewing)	0·002
Thin sheet iron	0·003
(1) Thick sheet iron	0·0033
(2) ,, ,, ...	0·0042 to 0·0045
Cast steel (annealed)	0·008
Tool steel	0·0094
Cast steel of minimum susceptibility...	0·0120
Cast iron	0·0162
Cast steel (tempered)	0·0250

V.—HYSTERESIS COEFFICIENTS (η).

(From the Experiments of DR. HOPKINSON.)

Metal.	Composition and Previous Treatment.	η
Cast iron	Annealed	0·00202
Soft Bessemer steel	0·045 per cent. of *C*, annealed	0·00262
,, Whitworth ,, ...	0·09 ,, ,, ,,	0·00257
,, ,, ,, ...	0·32 ,, ,, ,,	0·00598
,, ,, ,, ...	0·80 ,, ,, ,,	0·00786
,, ,, ,, ...	0·32 ,, tempered in oil	0·00954
,, ,, ,, ...	0·89 ,, ,, ,,	0·01844
Siliceous steel	3·44 ,, of *Si* (forged) ...	0·00937
,, ,, ...	,, ,, annealed ...	0·00784
,, ,, ...	,, ,, tempered in oil	0·01242
Manganese steel...	4·78 ,, of *Mn* (forged) ...	0·05963
,, ,, ...	,, ,, ,, annealed ...	0·04146
,, ,, ...	8·74 ,, ,, ,,	0·08184
,, ,, ...	4·73 ,, tempered in oil	0·06706
Chrome steel	0·62 ,, of *Cr* (forged) ...	0·01179
,, ,, ...	1·2 ,, ,, ...	0·01851
,, ,, ...	0·62 ,, annealed...	0·00897
Grey cast iron	3·47 of *C*, 0·17 per cent. *Mn*...	0·01826
White cast iron	2·04 ,, of *C*, 0·39 per cent. *Mn*	0·01616

VI.—Table of Values of $\eta \,.\, B^{1 \cdot 6}$.

(See p. 49.)

B	Value of $\eta B^{1 \cdot 6}$ for			B	Value of $\eta B^{1 \cdot 6}$ for		
	$\eta = 0 \cdot 002$	$\eta = 0 \cdot 003$	$\eta = 0 \cdot 004$		$\eta = 0 \cdot 002$	$\eta = 0 \cdot 003$	$\eta = 0 \cdot 004$
500	41 6	62·4	83·2	10,500	5 432	8,148	10,864
1,000	126 2	189 3	252·4	11,000	5,850	8,775	11 700
1,500	241 2	361 8	482·4	11,500	6,282	9,423	12 564
2,000	382·6	573 9	765·2	12,000	6,726	10,089	13,452
2,500	546·4	819·6	1,092·8	12,500	7 178	10,767	14 356
3,000	731·8	1,097·7	1,463 6	13,000	7,642	11,463	15,284
3,500	936·8	1,405·2	1,873 6	13 500	8,120	12,180	16,240
4,000	1,160	1,740	2,320	14,000	8,606	12 909	17,212
4,500	1,400	2,100	2,800	14 500	9,160	13,740	18,320
5,000	1 657	2 486	3,314	15 000	9 614	14,421	19,228
5,500	1,932	2,899	3,864	15,500	10,124	15,186	20,248
6,000	2,222	3,333	4,444	16,000	10 658	15,987	21,316
6,500	2 522	3,783	5,044	16,500	11,196	16,794	22,392
7,000	2,840	4,260	5,680	17,000	11,740	17,610	23 480
7,500	3,166	4,749	6,332	17,500	12,296	18,444	24 592
8,000	3 516	5 274	7,032	18,000	12,868	19,302	25 736
8,500	3,872	5,808	7,744	18,500	13 444	20,166	26,888
9,000	4,244	6,366	8,488	19,000	14 034	21,051	28,068
9,500	4,626	6,939	9,252	19 500	14 624	21,936	29,248
10,000	5,022	7,533	10,044	20,000	15,226	22,839	30,452

Hysteresis loss $= \eta \,.\, B^{1 \cdot 6} \omega V 10^{-7}$.

VII.—Table of Values of $\lambda^{0 \cdot 6}$.

(See p. 76.)

λ	$\lambda^{0 \cdot 6}$	λ	$\lambda^{0 \cdot 6}$
0·1	0 251	0·6	0·736
0·2	0·381	0·7	0·807
0·3	0·486	0·8	0·875
0·4	0·577	0·9	0·938
0·5	0·559	1·0	1·000

VIII.—TABLE OF VALUES SATISFYING THE EQUATION $\frac{(1 - \tau)^{0·6}}{1 + \tau} = A.$

(See p. 76.)

A	τ	A	τ
0	1	0·439	0·50
0·085	0·95	0·481	0·45
0·132	0·90	0·525	0 40
0·173	0 85	0·571	0·35
0·212	0·80	0·620	0·30
0 248	0·75	0·673	0 25
0·286	0·70	0·730	0·20
0·323	0·65	0·789	0·15
0·360	0·60	0·853	0·10
0·400	0·55	0 922	0·05

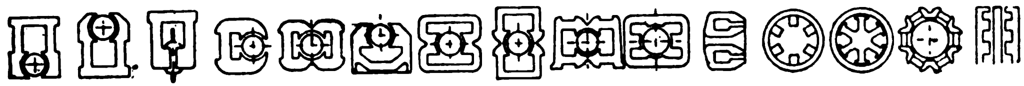
Hence $\tau = 1 - A$ (approximately).

IX.—TABLE OF VALUES OF $x = \frac{4·6\delta}{\xi} \log \left(1 + \frac{\xi c}{\delta}\right)$. (See p. 162.)

—	c	δ in Centimetres.					
		0·3	0·6	0·9	1·2	1·5	2·0
$a = 180°$	2·5	0·63	1·01	1 30	1·54	1·75	2·03
	5	0·76	1·26	1·67	2·02	2·34	2·77
	7 5	0·84	1·41	1·89	2·31	2·69	3·24
	10	0·89	1·52	2 05	2·52	2·95	3 58
	15	0·96	1·67	2·28	2·83	3·32	4·07
$a = 150°$	2·5	0·72	1·16	1·45	1·70	1·92	2 22
	5	0·87	1·47	1·88	2·27	2·60	3·08
	7·5	0·96	1·65	2·14	2·62	3·04	3·62
	10	1·03	1·78	2·34	2·87	3·34	4·04
	15	1·12	1·97	2·60	3·23	3·87	4·62
$a = 120°$	2·5	0·83	1·30	1·65	1·92	2·15	2·45
	5	1·03	1·67	2·19	2 60	2·98	3·50
	7·5	1·14	1·89	2·51	3·03	3·50	4·16
	10	1 22	2·05	2·75	3·34	3·87	4·65
	15	1·45	2·28	3·08	3·79	4·43	5·38
$a = 90°$	2·5	0·99	1·45	1·72	1·86	1·92	2·76
	5	1·26	2·02	2·61	3 09	3·50	4·06
	7·5	1·41	2·31	3·03	3·64	4·17	4·90
	10	1·52	2·52	3·34	4·04	4·67	5·55
	15	1·68	2·83	3·78	4·62	5·38	6·5

X.—Table of Magnetic Leakage Coefficients.*

(See p. 153.)



Kilowatts.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Kilowatts.
0·1	2·0	1·75	—	1·9	—	1·50	1·50	—	—	—	—	—	—	—	—	0·1
0·25	1·8	1·60	—	1·75	2·00	1·40	1·40	—	—	—	—	—	—	—	—	0·25
0·5	1·7	1·50	2·00	1·65	1·90	1·35	1·35	1·80	1·90	—	—	—	—	—	—	0·5
1	1·65	1·45	1·90	1·60	1·80	1·30	1·30	1·70	1·75	—	—	—	—	—	—	1
2·5	1·6	1·40	1·80	1·55	1·70	1·28	1·28	1·60	1·65	1·75	1·60	1·50	1·40	1·90	2·00	2·5
5	1·55	1·35	1·75	1·50	1·65	1·25	1·25	1·55	1·60	1·65	1·50	1·40	1·35	1·80	1·90	5
7·5	1·50	1·30	1·70	1·45	1·60	1·22	1·22	1·50	1·55	1·60	1·45	1·35	1·32	1·70	1·80	7·5
10	1·45	1·28	1·65	1·40	1·55	1·20	1·20	1·45	1·50	1·55	1·40	1·32	1·30	1·65	1·70	10
25	1·40	1·25	1·60	1·35	1·50	1·18	1·18	1·40	1·45	1·50	1·35	1·30	1·28	1·60	1·65	25
50	1·35	1·22	1·55	1·32	1·45	1·15	1·15	1·35	1·40	1·45	1·30	1·28	1·25	1·55	1·60	50
100	1·30	1·20	1·50	1·30	1·40	1·12	1·12	1·30	1·35	1·40	1·25	1·25	1·22	1·50	1·55	100
200	1·25	—	—	—	—	—	—	—	—	1·38	1·22	1·22	1·20	1·45	1·50	200
300	1·20	—	—	—	—	—	—	—	—	1·35	1·20	1·20	1·18	1·40	1·45	300
500	—	—	—	—	—	—	—	—	—	—	—	1·18	1·15	1·35	1·40	500
1,000	—	—	—	—	—	—	—	—	—	—	—	1·16	1·12	1·30	1·35	1,000
2,000	—	—	—	—	—	—	—	—	—	—	—	1·15	1·10	1·25	1·30	2,000

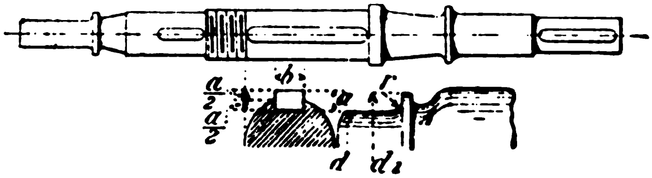
* From Wiener, *Electrical Engineer* (New York), 1893.

XI.—Dimensions of Keys.

(See p. 260.)

System of Jules Römmele (modified).

Applicable to Hubs in Cast Iron or in Gunmetal; in the latter case two key must be used.



Diameter of Shaft. d	Single Key.		Two Keys.	
	a	b	a	b
mm.	mm.	mm.	mm.	mm.
16 to 20	5	7	4	6
21 ,, 25	5	8	4	6
26 ,, 30	6	10	5	7
31 ,, 35	7	11	5	8
36 ,, 40	7	12	6	10
41 ,, 45	8	13	6	10
46 ,, 50	9	15	7	11
51 ,, 55	10	16	7	12
56 ,, 60	10	17	8	13
61 ,, 65	11	18	8	13
66 ,, 70	12	20	9	15
71 ,, 75	13	21	9	15
76 ,, 80	13	22	10	17
81 ,, 85	14	24	10	17
86 ,, 90	14	25	11	18
91 ,, 95	15	26	12	20
96 ,, 100	16	28	13	21
101 ,, 110	17	30	13	22
111 ,, 120	18	32	14	24
121 ,, 130	19	34	14	25
131 ,, 140	20	36	15	26
141 ,, 150	21	38	16	28
151 ,, 160	22	40	17	30
161 ,, 170	23	42	18	32
171 ,, 180	24	44	19	34
181 ,, 190	25	46	20	36
191 ,, 200	26	48	21	38
201 ,, 220	28	52	22	40
221 ,, 240	30	56	23	42
241 ,, 260	32	60	24	44
261 ,, 280	34	64	25	46
281 ,, 300	36	68	26	48

XII.—Calculation of the Size of Pulleys.

(See p. 276.)

$$b = c \frac{\text{H.P.}}{v};$$

H.P. = the number of horse-power transmitted ;

v = the speed of the belt, in metres per second.

b = the breadth of the belt, in centimetres.

$\frac{\text{H.P.}}{v}$	0·15	0·25	0·5	0·75	1	1·5	3	6	10	16·7*	29*	35†
c	48	39	24	20	17	15	10	7	6·5	6	4·9	3·7

* Tramway generator, Westinghouse Company.

† Steam-engine, J. Farcot, Saint-Ouen.

AMO

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